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Design and Implementation of Hybrid Fuzzy Control of a Magnetic Levitation System

Nasir Sattar[1], M. Kamran Liaquat Bhatti[1], Tahir Mahmood[1], Waqar Tahir[1], M. Kashif [2] and M. Yasin Mohsin [2]
[1]NFC Institute of Engineering and Technology- 66000, Pakistan.
[2]COMSATS University Islamabad, Sub Campus Sahiwal- 57000, Pakistan.
Corresponding Author's email: Nasir Sattar (nasir.sattar777@gmail.com).

Abstract- **In this research paper scientific model of the levitation system based on the magnetic field has been implemented with the help of the fuzzy-logic controller. The behaviour of alluring (maglev) mainly based on the PID-controller being used. Therefore, a controller based on PID has been organized to control efficiently and get the desired performance of the maglev system under study. But, as evident from the literature review, a PID controller has its limitations and is typically undefined in the situation of changing the load because PID controllers have fixed constraints. Due to these limitations, a controller that is based on fuzzy logic has been designed to overcome these problems. By using the fuzzy logic, again has been selected for the PID-controller by using the different values of load and set the reference value to calculate the gain error. Best suited membership functions have been used to fuzzifier the gain parameters. An optimal inference engine has been designed to map inputs to the corresponding outputs. Finally, a de-fuzzifier has been designed to get crisp values which reflect the gain constraints of the designed PID Regulator. This fuzzy controller supervises the conventional PID controller to automatically adjust its parameters to control the maglev system even with varying load and varying air gap changes.**

***Index Terms*— Maglev, Fuzzy Controller, Efficiency**

I. INTRODUCTION

These days, attractive levitation frameworks have been extensively executed for plenty of fields in our daily life. Maglev is being used extensively in transport engineering. It includes maglev trains, flying cars, personal rapid transit (PRT) etc. Ring spinning technology for making yarn is based on maglev[1-3]. Maglev can be depicted as a technique in which an item is suspended with no contact with any surface by magnetic forces[4-6]. A simple maglev system has been shown in Fig-1 that is based on the fuzzy-controller. In this network, a ball has been used as an object. The position of the object has been detected with the help of detector circuit that is placed in the right angle of the object.

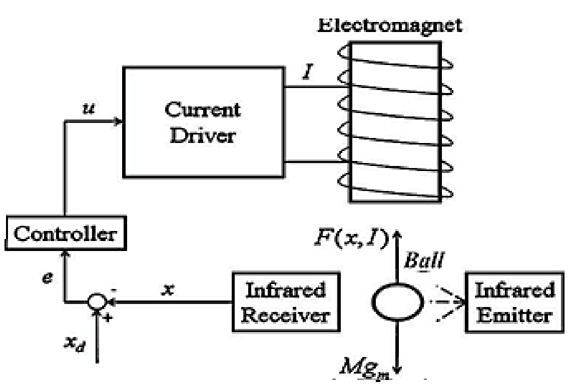

FIGURE 1: Maglev Model

Afterwards detector circuit produces a signal and gives the command to the main controller in the form of voltage. The auxiliary controller converted this voltage into Alternating current and provided to the coil circuit. When the current passes through the coil, the magnetic force will be produced w.r.t direction and magnitude of the current. Due to the attraction of forces, this object will be move according to the magnitude and direction of forces. At the same time controller produce a signal to overcome the vibration of the object. In this way, the controller nullifies the movement of the object, so the object keeps suspended [7-10].

In this research paper controller that is based on the fuzzy is used to tune the predictable PID controller. They have used a fuzzy inference engine that alters the gains of the controller. The proposed system is efficient and self-adjusting when compared to a simple controller that is based on PID. A PID-controller remains a good option for controlling certain systems, but they fail on air gap and load variations. Fuzzy tuned PID overcomes these limitations [4]. To efficiently control and optimize a maglev system a simple PID controller is not enough. For the optimum performance and response, an intelligent controller needs to be designed, which must supervise the output of the PID controller being used. Therefore, a supervisory controller based on fuzzy logic has been suggested to automatically adjust the gains of the conventional "PID" controller and optimize the performance parameters of a maglev system [11-18].

This examination aims to implement a controller to provide the optimal dynamic response of Maglev system. This will be achieved by incorporating fuzzy logic with conventional controllers. This model has been designed in MATLAB, and all the performance significant is compared with other controllers [6].

II. METHODOLOGY

In the proposed strategy, A chronological approach has been used in this section to describe the model of maglev system. A PID Controller is designed to get the desired performance. The "PID" controller is further improved by applying "fuzzy" logic.

A. TRANSFER FUNCTION

To obtained the transfer function of (maglev) system, the simplest model has been developed as shown in Fig-2.

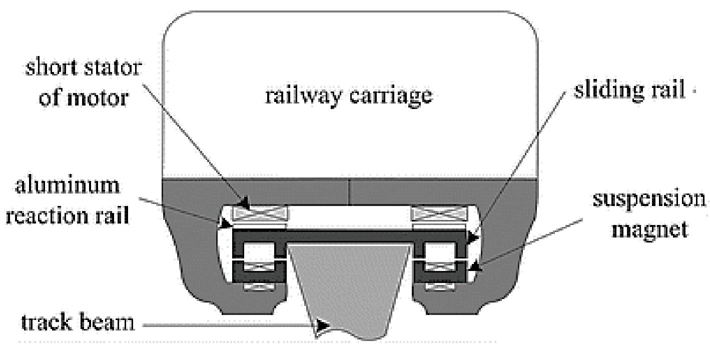

FIGURE 2: Maglev-Model with Fixed Reference (Hutterer *et al*., 2020)

Eight magnets have been used in this network to supported the train, and it consists of six unique movements. However here just one movement is thought of, and that is to suspend the train over the track upward way. Here H=Altitude of the train from the base point or track and Y= Altitude of the train from the lower contact point with the track. So 'A' is the hole separation among train and the track.

$$A = Y - H \tag{1}$$

Take 1st and 2nd derivative of the equation (1)

$$\dot{A} = \dot{Y} - \dot{H} \tag{2}$$

$$\ddot{A} = \ddot{Y} - \ddot{H} \tag{3}$$

The model of maglev in the form electrical constraints is shown in Fig-3. This model is obtained by (2) and (3).

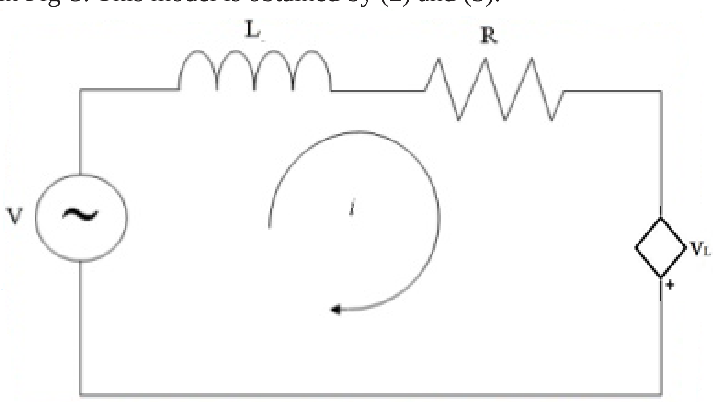

FIGURE 3: Maglev Model in Forms of Electrical Concentrates

The force is produced by the electromagnets that is depend upon the amount of current flowing through a circuit as described in equation 4.

$$v_L = L\frac{di}{dt} \tag{4}$$

Three variables are defined in the form of state variable is

$$x_1 = A \; , \tag{5}$$

$$x_2 = \dot{A} \tag{6}$$

$$x_3 = I \tag{7}$$

$$\dot{x}_1 = (0)x_1 + (1)x_2 + (0)x_3 + (0)v \tag{8}$$

$$\dot{x}_2 = \left(\frac{Q}{M}\right)x_1 + (0)x_2 + \left(\frac{-P}{M}\right)x_3 + (0)v \tag{9}$$

$$\dot{x}_3 = (0)x_1 + \left(\frac{Q}{P}\right)x_2 + \left(\frac{-R}{L}\right)x_3 + \left(\frac{1}{L}\right)v \tag{10}$$

The flow graph of state variable is shown in Fig-4

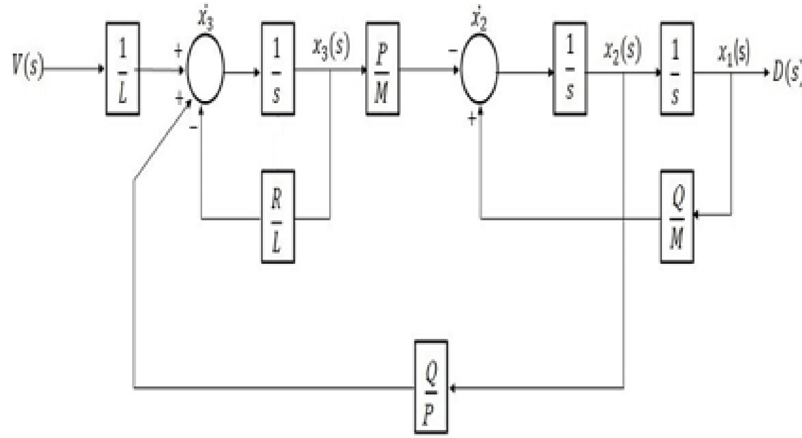

FIGURE 4: Flow Graph of State-Variable

The matrix derived from the flow graph is given below

$$|sI - A| = \begin{vmatrix} s & -1 & 0 \\ \frac{-Q}{M} & s & \frac{P}{M} \\ 0 & \frac{-Q}{P} & s + \frac{R}{L} \end{vmatrix} = 0$$

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ \frac{Q}{M} & 0 & \frac{-P}{M} \\ \frac{K_1}{L} & \frac{H}{P} + \frac{K_2}{L} & \frac{-R}{L} + \frac{K_3}{L} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 1/L \end{bmatrix} [v]$$

All the values have been calculated with the design model and drive the transfer function form matrix is described in equation 11.

$$T_L(s) = \frac{-\frac{1}{2}}{s^3 + \frac{16}{2}s^2 + \frac{58}{2}s + 25.2} \tag{11}$$

B. DESIGN OF SUPERVISORY CONTROLLER

The design model of supervisory controller is depicted in Fig-5. A customary PID-controller has been utilized as an essential controller and a controller based on fuzzy logic has been used in the administrator controller. The administrator controller controls the parameters associated with system as well as generate the signal when customary controller fails to generate signals.

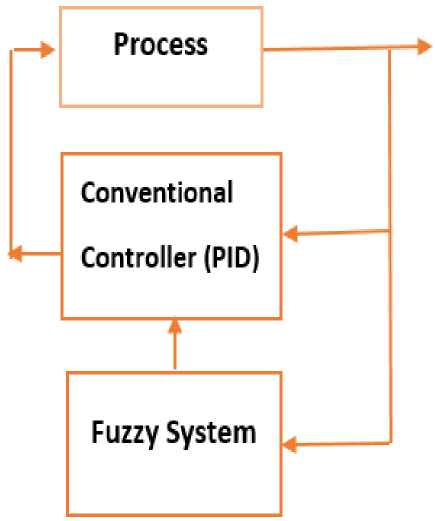

FIGURE 5: Design of Supervisory-Controller

C. BUILDING BLOCKS OF A FUZZY CONTROLLER

The crisp input is provided to the fuzzifier that's converters the crisp input into fuzzy input. Afterward fuzzy input is further provided into interface engine that predicts the fuzzy output. Rule base is used to control the condition. In the 3rd step fuzzy output is further feed into Defuzzifier block, in which fuzzy output is again change into Crisp output as shown in Fig-6.

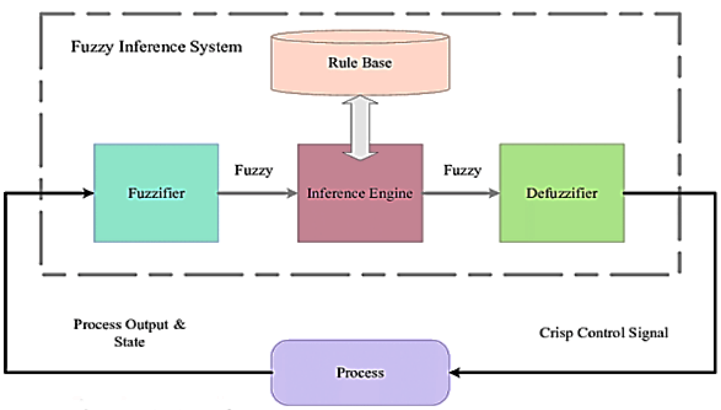

FIGURE 6: Building Blocks of Fuzzy Controller

D. DeDEGREE OF MEMBERSHIP

In fuzzy logic, all quantities are a function of a degree which varies between 0 and 1. A '0' value indicates that a quantity does not belong to a referred set. While '1' value indicates its full membership of that set. All intermediate values have partial degree of membership [9, 19].

E. CENTER OF GRAVITY

In control and engineering applications, mostly 'center of gravity', 'maximum' and 'center average defuzzifier are used. In this research, center of gravity defuzzifier is used to get the desired crisp output. A brief description of center of gravity defuzzifier given below [10].

$$y^* = \frac{\int y\mu_B(y)\,dy}{\int \mu_B(y)\,dy} \qquad (12)$$

Where y* represents defuzzifier crisp output and μ_B represents aggregated membership function of fuzzy set B.

F. CONTROL OF SUPERVISORY CONTROLLER

An efficient method of modelling the controller that is based on fuzzy is shown in Fig-7 and procedure to tuned the controller is under.

- Set the reference value for generating the error signal
- Set the inputs variables for the system
- Tuned the controller that is based on Fuzzy to control the parameters of simple PID controller.
- Now we will tune PID controller parameters using fuzzy logic. Let us consider that we have two inputs which are "error-signal' and "deviation in error signal". "Error signal" is the observed value deviated from the true or expected value. Whereas, "Change in error" is the deviated value in comparison with the previous error generated.
- Simulate the PID controller to maglev system to regulate the power output
- Compare the output signal with reference signal.
- If any difference is found between original signal and reference signal, an error signal will be generated and Fuzzy controller control the parameters and keep the system in stable mode.

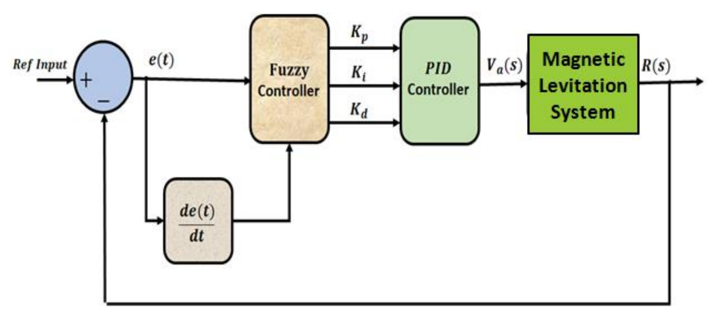

FIGURE 7: Building Blocks of Fuzzy Controller (Lu *et al*., 2020)

The plot of error signal and deviation in error signal is shown in Fig-8 and Fig-9. These two signals are used to tuned the gain of PID controller.

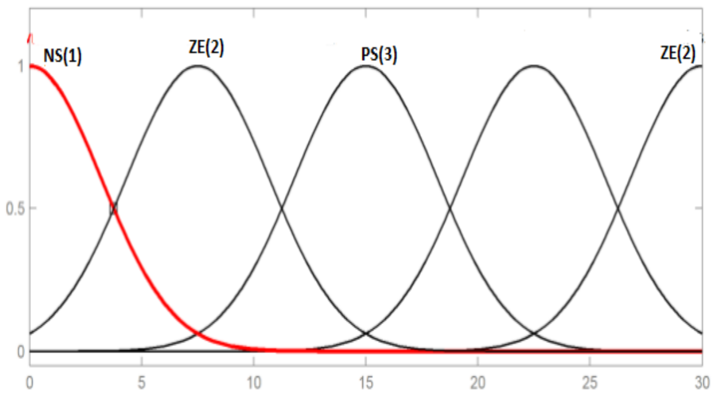

FIGURE 8: Plot for Error Signal

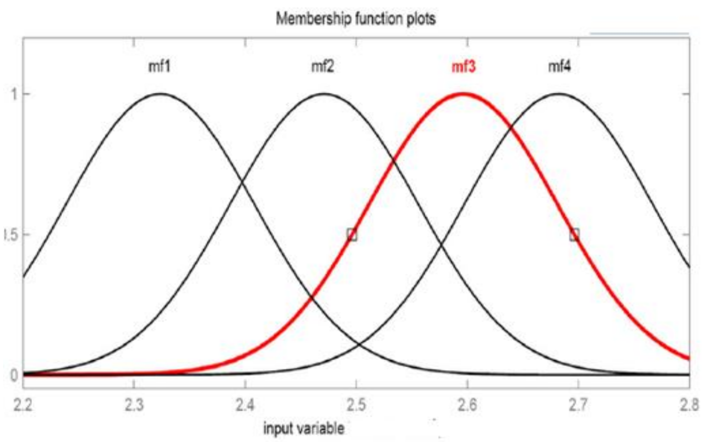

FIGURE 9: Plot for Deviation in Error Signal

III. RESULTS AND DISCUSSION

The results of both PID controlled system and Fuzzy tuned PID controlled system is analyzed. The stability of both these systems is examined using Root Locus technique. The system behavior is analyzed including controller and without PID controller and compare their results in Table-1 and step response of PID controller is shown in Fig-10

Table 1: Comparative Analysis of System Parameters with and Without PID Controller

	Without PID controller	With PID controller
Rise time (s)	1.85	0.50
Settling time (s)	3.55	1.02
Overshoot (%)	0	0.40

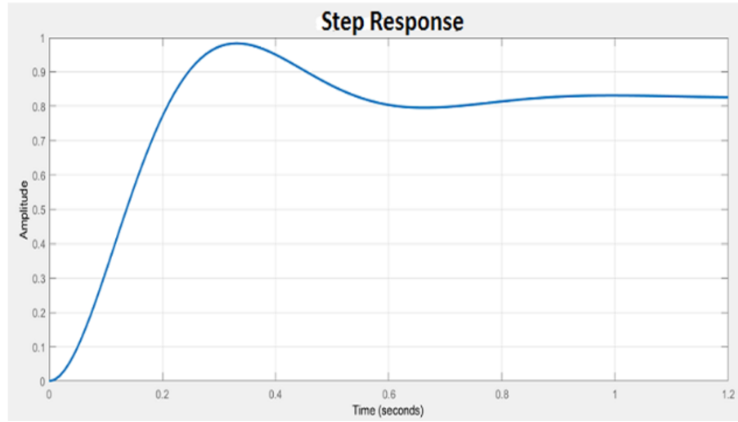

FIGURE 10: Step Response of Controller Based on PID

It has been observed that by using PID controller, the response of rising time has been improved. With increasing the overshoot, the system become faster and more stable.To analyze the stability of the system, root-locus analysis is essential. From the Fig-11 it has been analyzed that, the complex pair $-1.35 \pm j0.56$ will converge at complex pair of zeros. The complex pair $-2.65 + j4.85$ and $-2.65 - j4.85$ will converge towards infinity at angles of 90^0 and 270^0 respectively. So, the roots will remain in the stable region as the gain varies towards infinity.

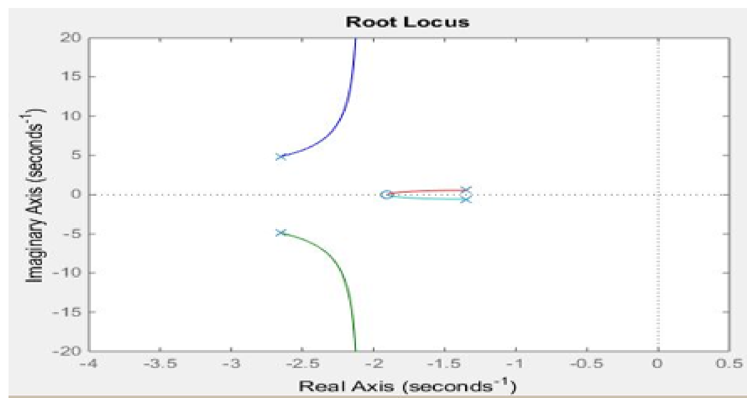

FIGURE 11: Root Locus of PID Controlled Maglev System

A THE RESPONSE OF A "FUZZY "TUNED CONTROLLER

To observe the response of the system using tuned fuzzy PID, the value of "error" and "deviation in error" has been selected between the range of -110 to 110.Using a fuzzy logic controller based on the PID controller, the output of the closed loop operation of the (maglev) has been improved compared to that of the traditional PID controller, as can be seen from the phase response given in Fig-12.

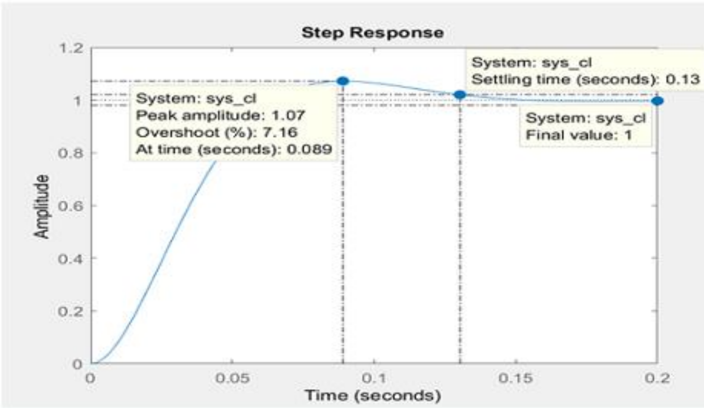

FIGURE 12: Step-Response of Tuned PID Controller Based on Fuzzy Logic

Similarly, by using the error value and deviation in error is compute the values of gain parameters within the defined range. For example, consider the case of K_p in Fig-13. At this stage the error value and "deviation in error" is zero, therefore, the proportional gain 'Kp' will be -137. As we change "error" values and "deviation in error values", proportional gain will alteration accordingly. Randomly we select "error" and "change in error" to be [50,50] respectively, the value of Kp is shown in Fig-14. It has been analyzed that, the value of Kp is -150 and error is 0.5.

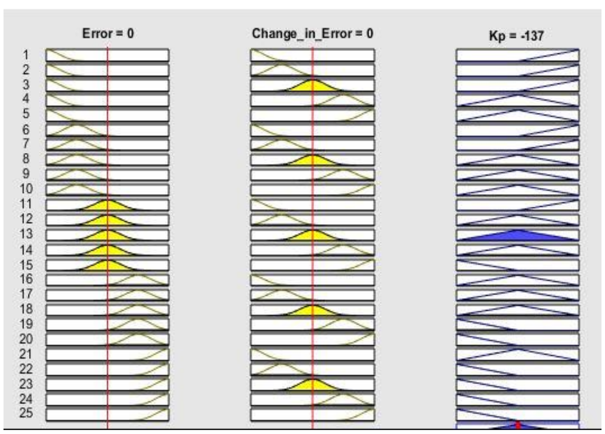

FIGURE 13: Value of Kp at [0 0]

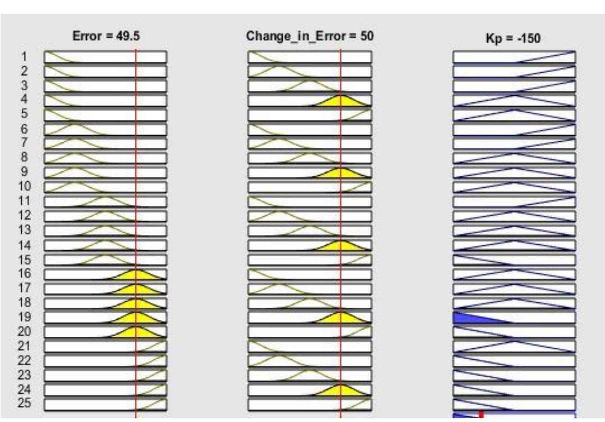

FIGURE 14: Value of Kp at [50 50]

The outcomes in Table-2 elaborates the error values and deviation in error values with system response. The Fuzzy supervisory controller alters the constraints of PID controller to obtain desired performance.

Table 2: Comparative Analysis of Error and Deviation in Error Values

Error, Deviation in Error	K_{Pro}	K_{int}	K_{der}
[0, 100]	-148.63	-154.97	-36.87
[-100, 0]	-126.83	-105.89	-28.48
[-75, 0]	-135.41	-124.82	-30.95
[0, 75]	-139.23	-136.02	-32.40
[-50, 0]	-136.14	-132.34	-31.66
[0, 50]	-136.26	-132.57	-31.69
[-25, 0]	-136.22	-132.30	-31.66
[0, 25]	-136.28	-132.61	-31.69
[-100, 100]	-136.30	-132.46	-31.68
[-50, 50]	-136.30	-132.46	-31.68

V. CONCLUSION

This research paper focuses on the objective to model a maglev system mathematically and design a controller to provide an optimal dynamic response of magnetic levitation (Maglev) system. This has been achieved by incorporating fuzzy logic with conventional controllers. In this research paper, a mathematical equation of maglev system and their transfer function has been carried out with the help of the state variable. The design and structure of both conventional controllers and fuzzy controllers have been implemented in MATLAB. Results from the simulation show that the settling time of the system has been reduced as compared when other controllers are used. Also, during the transient period, the design and instant load changes in the system has been robust as compared to the conventional controllers. It has been observed that with the help of a hybrid fuzzy controller, the settling time of the system has been improved and the system efficiency has been improved.

REFERENCES

[1] A. Mughees and S. A. Mohsin, "Design and Control of Magnetic Levitation System by Optimizing Fractional Order PID Controller using Ant Colony Optimization Algorithm," in IEEE Access, doi: 10.1109/ACCESS.2020

[2] A. Morsi, S. M. Ahmed, A. M. Mohamed and H. S. Abbas, "Model Predictive Control for an Active Magnetic Bearing System," 2020 IEEE 7th International Conference on Industrial Engineering and Applications (ICIEA), Bangkok, Thailand, 2020

[3] H. M. M. Adil, S. Ahmed and I. Ahmad, "Control of MagLev System Using Super twisting and Integral Backstepping Sliding Mode Algorithm," in IEEE Access, vol. 8, pp. 51352-51362, 2020

[4] I. Iswanto and A. Ma'arif, "Robust Integral State Feedback Using Coefficient Diagram in Magnetic Levitation System," in IEEE Access, vol. 8, pp. 57003-57011, 2020

[5] J. Zhang, X. Wang and X. Shao, "Design and Real-Time Implementation of Takagi–Sugeno Fuzzy Controller for Magnetic Levitation Ball System," in IEEE Access, vol. 8, pp. 38221-38228, 2020, doi: 10.1109/ACCESS.2020

[6] M. Hypiusová, D. Rosinová and A. Kozáková, "Comparison of State Feedback Controllers for the Magnetic Levitation System," 2020 Cybernetics & Informatics (K&I), Velke Karlovice, Czech Republic, 2020

[7] M. Hutterer, D. Wimmer and M. Schröedl, "Stabilization of a Magnetically Levitated Rotor in the Case of a Defective Radial Actuator," in IEEE/ASME Transactions on Mechatronics, doi: 10.1109/TMECH.2020

[8] Q. Gao, G. Yan, H. Zou, W. Zhang, Z. Peng and G. Meng, "Density-Based Measurement and Manipulation via Magnetic Levitation Enhanced by the Dual-Halbach Array," in IEEE Sensors Journal, vol. 20, no. 4, pp. 1730-1737, 15 Feb.15, 2020

[9] S. Dey, J. Dey and S. Banerjee, "Optimization Algorithm Based PID Controller Design for a Magnetic Levitation System," 2020 IEEE Calcutta Conference (CALCON), Kolkata, India, 2020

[10] T. Soni, J. K. Dutt and A. S. Das, "Parametric Stability Analysis of Active Magnetic Bearing Supported Rotor System with a Novel Control Law Subject to Periodic Base Motion," in IEEE Transactions on Industrial Electronics, vol. 67, no. 2, pp. 1160-1170, Feb. 2020

[11] X. Lu, F. Xu, X. Xu, T. Zheng and R. Peng, "Directed-Driven 8-Phase Magnetically Levitated Rotary Table Based on an Analytical-Numerical Model," in IEEE Access, vol. 8, pp. 31159-31170, 2020.

[12] Khan MN, Jamil M, Gilani SO, Ahmad I, Uzair M, Omer H. Photo detector-based indoor positioning systems variants: A new look. Computers & Electrical Engineering. 2020 May 1;83:106607.

[13] Kashif H, Khan MN, Altalbe A. Hybrid Optical-Radio Transmission System Link Quality: Link Budget Analysis. IEEE Access. 2020 Mar 18;8:65983-92.

[14] Zafar K, Gilani SO, Waris A, Ahmed A, Jamil M, Khan MN, Sohail Kashif A. Skin Lesion Segmentation from Dermoscopic Images Using Convolutional Neural Network. Sensors. 2020 Jan;20(6):1601.

[15] Uzair M, D DONY RO, Jamil M, MAHMOOD KB, Khan MN. A no-reference framework for evaluating video quality streamed through wireless network. Turkish Journal of Electrical Engineering & Computer Sciences. 2019 Sep 18;27(5):3383-99.

[16] Khan MN, Gilani SO, Jamil M, Rafay A, Awais Q, Khawaja BA, Uzair M, Malik AW. Maximizing throughput of hybrid FSO-RF communication system: An algorithm. IEEE Access. 2018 May 25;6:30039-48.

[17] U. Saleem, M. Khan, and G. Abbas, "Design Layout and Installation Methodology of Cable Trays in a Distribution Substation of Pakistan", Pakistan J Engg & Tech, vol. 2, no. 2, pp. 6-11, Dec. 2019.

[18] Y. Lan, J. Li, F. Zhang and M. Zong, "Fuzzy Sliding Mode Control of Magnetic Levitation System of Controllable Excitation Linear Synchronous Motor," in IEEE Transactions on Industry Applications, doi: 10.1109/TIA.2020

[19] Z. Ahmad, M. Umar, S. Shaukat, S. Hassan and S. Lupin, "Design and Performance Enhancement of a Single Axis Magnetic Levitation System Using Fuzzy Supervised PID," 2020 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (EIConRus), St. Petersburg and Moscow, Russia, 2020