International Journal of Emerging Science and Engineering (IJESE)
ISSN: 2319–6378 (Online), Volume-12 Issue-10, September 2024

Load Frequency Control of a Single Area System Using Fuzzy Logic Controller and Comparison with Integral and PID Controller

Aditya Ranjan Buragohain, Nipan Kumar Das

***Abstract:** Today's power system is massive, complex and very dynamic. With innovations such as power electronics and renewable energy integration, the power system becomes more complex. Controlling the frequency with respect to load is most important in a power system because the system will lose its synchronism if the frequency changes. When the load demand is greater than the actual power generated, then the system frequency goes down and this condition is called under frequency condition. In some other cases when the load decreases then the system frequency will go up and this condition is called the over-frequency condition. In both cases, the system frequency fluctuates from its normal frequency range. This paper demonstrates the use of a fuzzy logic controller in a single area system to control the change in load frequency and a comparison with traditional (INTEGRAL AND PID) controllers. The simulation of the entire system is performed on the MATLAB Simulink.*

***Keywords:** Load Frequency Control (LFC), Fuzzy Logic Control (FLC), Proportional-Integral-Derivative (PID) controller, Integral Controller*

I. INTRODUCTION

The main objective of load frequency control is to maintain the power balance between the interconnected areas and to control the power flow in the tie lines. For the smooth operation of any power system, the system frequency must be in its normal frequency range otherwise the whole system may get collapse. It may lead to loss of consumer, difficulty in parallel operation of alternator, increase in transformer loss, difficulty in controlling of electric drives, etc [1].

Every machine has a speed governor and its function is to monitor the frequency in the generator or system. The speed governor controls the valve opening and closing based on the frequency generated in the generator which is the primary control otherwise we often need the secondary control. Secondary control involves controlling the loading on different plants when the primary control is not adequate enough for frequency control.

The various methods of secondary control are - Flat Frequency Control, Parallel Frequency Control, and Flat Tie-Line Control.

The above mentioned Frequency Controls has many limitations such as slower response and accuracy which leads to consumption of much time to become stable. So, we use Traditional Controller such as I, PI, PID [2].

Electro-hydraulic PID-based governor or controller replaces the mechanical components of the dash-pot and piston with electrical components. As these electrical components are static in nature, they don't have inertia. For this, their response time is faster as compared to mechanical hydraulic governors. PID Controller provides robust satisfactory control of frequency by changing the parameters of P, I, and D gain but we know that load demands in power systems are variable in nature. In fact, the load demand continuously changes throughout the day [3].

On the other hand, PID controllers often exhibit poor control performance when dealing with integrating processes and processes with large time delays. Additionally, they struggle to effectively handle ramp-type set-point changes or slow disturbances. PID Controllers have the limitation that their parameters cannot be tuned online for continuous load variations. Due to this, the PID Controller cannot provide the best optimal response for every load variation. So we need satisfactory values of P, I, and D for all load conditions [4].

A human expert can easily understand the behavior of an FLC, as knowledge is expressed using intuitive, linguistic rules. In contrast with traditional linear and nonlinear control theory, an FLC is not based on a mathematical model and is widely used to solve problems under uncertain and vague environments with high nonlinearities. The Fuzzy Logic Control has the ability that if we define the rules for all conditions separately then it will provide the best response for its condition every time. That means it can provide the best response simultaneously for all the operating conditions [5]. In this paper, a Fuzzy Logic Controller (FLC) is used. This type of controller adds a pole at the origin results in a reduction of the steady-state error. System load is never steady but using controllers this can be controlled. In uncontrolled cases, there is more oscillation, and negative overshoot is observed but when compared to conventional type controllers and proposed work, it gives better performances of dynamic responses [6].

Manuscript received on 16 June 2024 | Revised Manuscript received on 10 August 2024 | Manuscript Accepted on 15 September 2024 | Manuscript published on 30 September 2024.
*Correspondence Author(s)

Aditya Ranjan Buragohain,* Department of Electrical Engineering, Jorhat Engineering College, Jorhat, Assam, India. E-mail ID: adityabgohain548@gmail.com, ORCID ID: 0009-0001-5926-1462

Nipan Kumar Das, Department of Electrical Engineering, Jorhat Engineering College, Jorhat, Assam, India. E-mail ID: niponkd.das@gmail.com

II. SYSTEM DYNAMICS

A single-area power system network consisting of thermal area is taken into account in this paper. The block diagram of the single-area power system is shown in Figure 1 which consists of a non reheat type turbine with a governor and a generating unit.

A. Modelling of the Thermal Area

The real power in a power system is controlled by controlling the position of the control valve to exert the flow of high-pressure steam through the turbine. The mathematical model can be developed which is based on small deviations around the nominal steady state. Let us assume that the steam is operating under steady state and delivering power from the generator at nominal speed or frequency (f). Under this condition, the transfer functions equation of the governor, turbine (Non-Reheat type turbine), and generator has been obtained and shown below [7].

$$\text{Governor Transfer Function} = \frac{K_g}{1 + ST_g}$$

$$\text{Turbine Transfer Function} = \frac{K_t}{1 + ST_t}$$

$$\text{Generator Transfer Function} = \frac{K_p}{1 + ST_P}$$

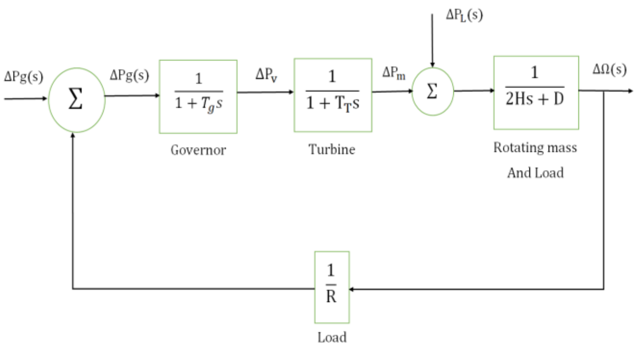

Fig. 1: Complete Block Diagram of the Single Area System

Where K_g, K_t, and K_p are the gains of the governor, turbine, and generator respectively. T_g, T_t, and T_p are the time constant of the governor, turbine and generator respectively.

III. FUZZY LOGIC CONTROLLER

Fuzzy means not clear. The fuzzy logic approach was presented by Lotfi Asker Zadeh in 1965. It is called a superset of boolean algebra. A fuzzy logic controller involves 3 stages - (1) Fuzzification (2) Inference or Interpretation (3) Defuzzification. Fuzzification is the process of converting the crisp input to a fuzzy quantity using a membership function stored in the knowledge base. Knowledge base comprised of database and linguistic control rule base. In the second stage of FLC, we formulate rules using linguistic variables that rely on system performance and experience. Then, we employ an interpreter to make decisions based on the input provided and the rule base. Defuzzification is the process of changing the fuzzified value into a crisp value or precise quantity [8][9][10][11][12][13][14].

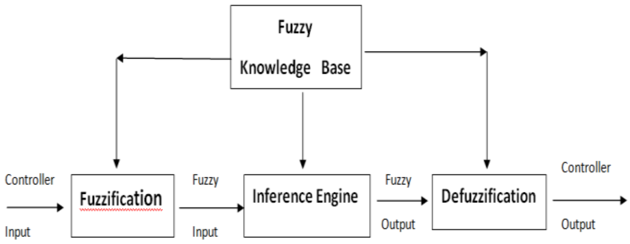

Fig. 2: Block Diagram of Fuzzy Logic Controller

IV. SYSTEM MODELLING

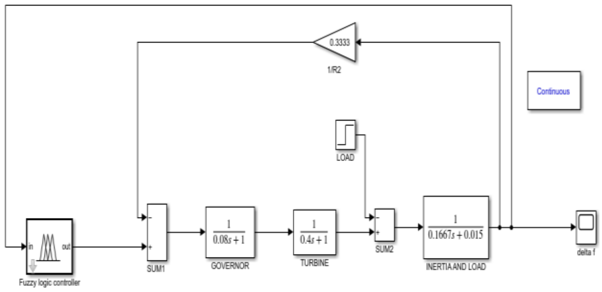

Fig. 3: Simulink Model of Thermal Plant with Fuzzy Logic Controller

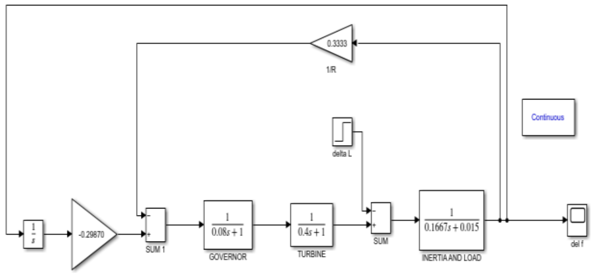

Fig. 4: Simulink Model of Thermal Plant with Integral Controller

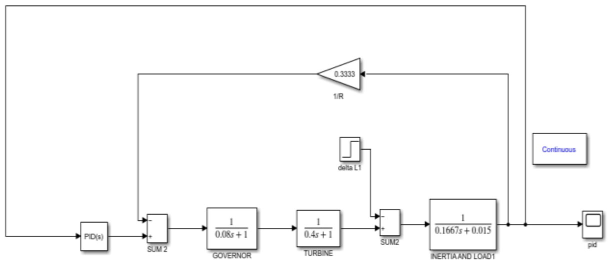

Fig. 5: Simulink Model of Thermal Plant with PID Controller

In Figures 3, 4, and 5 we have seen the MATLAB Simulink model of a thermal power plant with the fuzzy logic controller, integral, and PID controller respectively [15]. The membership function taken for the input i.e. the change in frequency is five in number. Membership functions are High Undershoot (HU), Low Undershoot (LU), Normal Frequency (NF), Low Overshoot (LO), High Overshoot(HO). The membership function taken for the output i.e. Valve Position is five in number. They are Full Closed (FC), Half Closed (HC), Normal Open (NO), Half Open (HO), and Full Open (FO).

Retrieval Number: 100.1/ijese.F451113060824
DOI: 10.35940/ijese.F4511.12100924
Journal Website: www.ijese.org

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

There is one input and one output to the fuzzy system which are Changes in Frequency and Valve Position respectively which is shown in Fig. 6

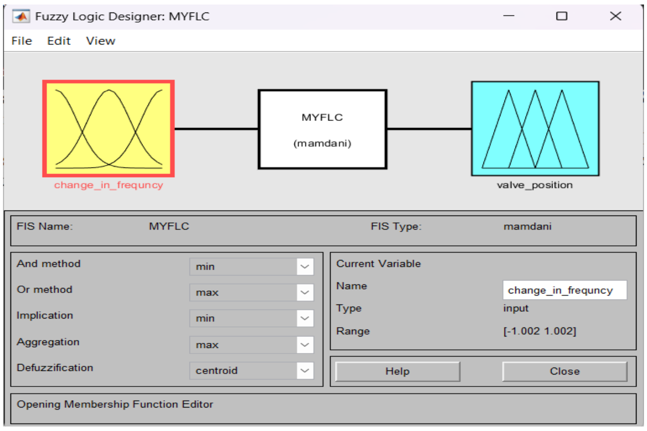

Fig. 6: Input and Output to the Fuzzy Editor

In this controller, triangular and trapezoidal membership functions are used for both input (Change in Frequency) and output (Valve Position) [16]. The membership functions for input and output are shown in Fig. 7 and Fig. 8 respectively. The rules highly depend on the membership function and they are set in an appropriate collection of input and output parameters [17][18][19][20][21]. The suitable Fuzzy Rules should be inserted into the fuzzy rule box which will be in the format that "If A is Good then Output is Good".After assigning the rules they will be saved as a file in FIS format. This file will be stored in the same folder as our Matlab file. We can then use this fuzzy file in the corresponding fuzzy block, using the appropriate notation. On simulating the respective simulation the following output will be generated which will have the advantages of reduction in settling time, meaning the system reaches stability more quickly. Additionally, there will be less fluctuation in frequency compared to what we got with a PID controller.

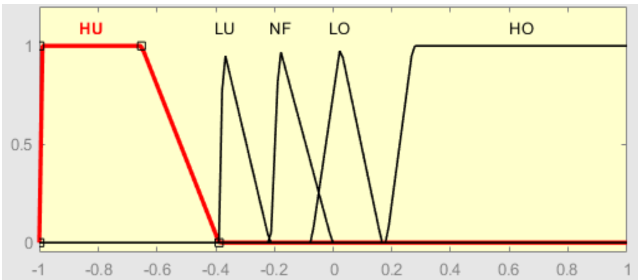

Fig. 7: Membership Function for Input

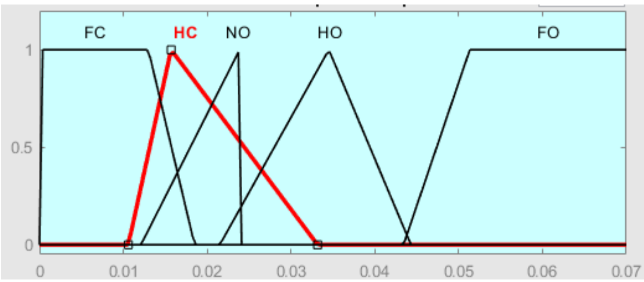

Fig. 8: Membership Function for Output

Table-1: Fuzzy Rule Base

Rules	Input	Output
Rule 1	LU	HO
Rule 2	NF	NO
Rule 3	LO	HC
Rule 4	HU	FO
Rule 5	HO	FC

Mamdani's method with Max-Min is used for fuzzy combinations. Defuzzification is the last stage of a fuzzy controller. Centroid method is used here for Defuzzification. The rules for this controller are shown in Table 1. In Fig. 4 and Fig. 5, the Simulink model of the thermal power plant with integral and PID controller is shown. The gain of the integral controller and PID parameters (K_p, K_i, K_d) are found using the trial and error method. (Best possible values for all the gains).

V. SIMULATION AND RESULT

In this research, MATLAB software is used along with the fuzzy logic toolbox to conduct simulations. In this paper, the investigation of load frequency control (LFC) for a single-area model of non-reheat turbine power systems is undertaken, employing fuzzy logic controller, integral, and PID controller. A disturbance of 0.02 p.u. is applied to the single-area system. The data utilized for this system is provided in the Appendix.

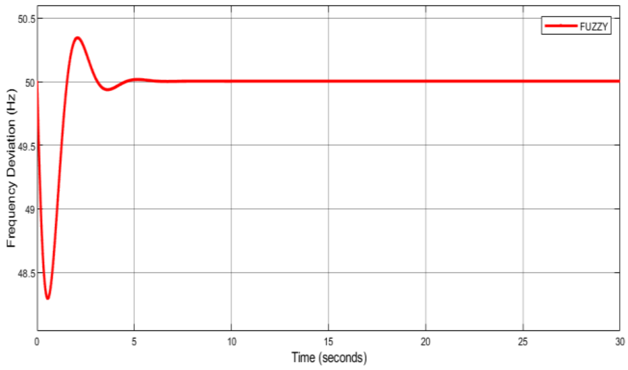

Fig. 9: Frequency Deviation of Proposed Fuzzy Logic for Single Area System

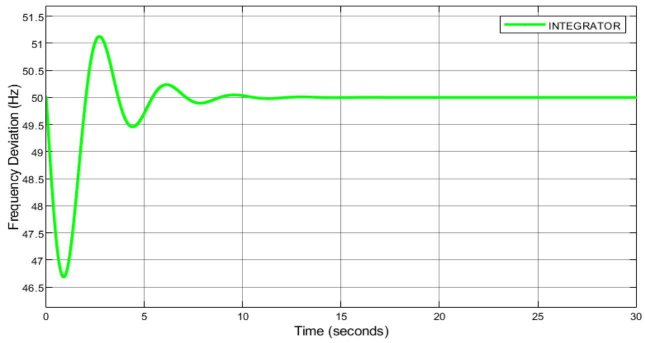

Fig. 10: Frequency Deviation of the Single Area with Integral Controller

Retrieval Number: 100.1/ijese.F451113060824
DOI: 10.35940/ijese.F4511.12100924
Journal Website: www.ijese.org

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

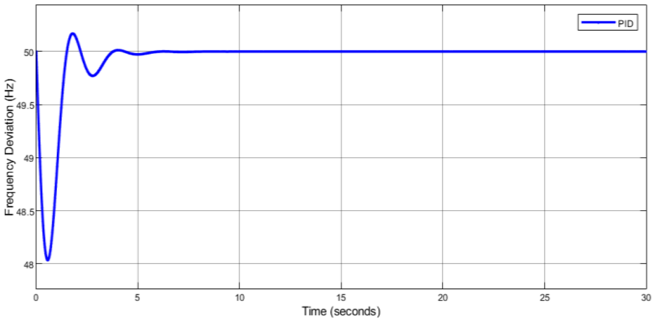

Fig. 11: Frequency Deviation of the Single Area with PID Controller

From the above figures (Fig.10, Fig.11, Fig.12) we have seen the frequency deviations of the single area system by using a Fuzzy logic controller, Integral controller, and PID controller respectively. We have seen a large undershoot in the case of the integral controller, a medium undershoot in the PID controller and a comparatively small undershoot in the Fuzzy controller. The statistical comparison of the responses in terms of settling- time and under-shoot is shown in Table 2. It could be easy to say that the proposed intelligent controller gives a small undershoot and settles fast as compared to PID controller in a literal sense.

The suitable values for PID parameters (K_p, K_i, K_d) and the gain of the integral controller (K_i) are shown in Table 3. The suitable parameters are found using the Trial and Error method.

Table-2: Comparison of Frequency Deviation of Single Area System

Controller	Settling Time (Second)	Undershoot
Fuzzy (Proposed)	6.243	0.602
Integral	14.006	15.345
PID	7.801	12.132

Table-3: Parameters for PID and Integral Controller

Controller	K_p	K_i	K_d
PID	- 0.3960	-0.5337	-0.0726
Integral	---------	- 0.29870	----------

The comparison graph shown in Figure 12 illustrates the results obtained by conventional PID, INTEGRAL controller, and fuzzy controller. From the responses above, it is evident that the performance of the fuzzy logic controller is better than that of the conventional PID and Integral controller in aspects like settling time. The transients are observed to take less time to die out. Moreover, the percentage of undershoot is very low as compared to Integral and conventional PID controller.

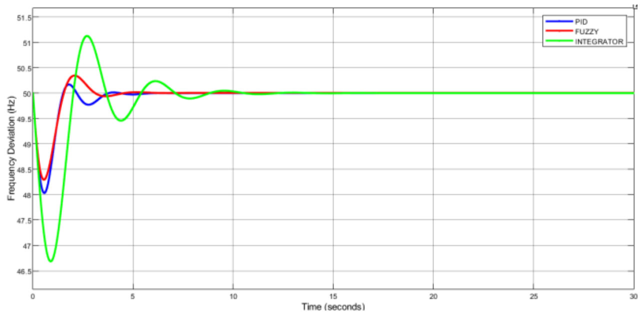

Fig. 12: Comparison of Deviations in Frequency in the Single Area System

VI. CONCLUSION

In this study, a fuzzy logic control approach is employed for load frequency control of an isolated or a single-area system. The proposed Fuzzy Logic Controller provides better dynamic performance and reduces the oscillation of the frequency deviation as compared to conventional PID and Integral controllers, with 0.02 per unit(p.u.) step load increment.

DECLARATION STATEMENT

After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

- **Conflicts of Interest/ Competing Interests:** Based on my understanding, this article has no conflicts of interest.
- **Financial Support:** This article has not been funded by any organizations or agencies. This independence ensures that the research is conducted with objectivity and without any external influence.
- **Ethical Approval and Consent to Participate:** The content of this article does not necessitate ethical approval or consent to participate with supporting documentation.
- **Data Access Statement and Material Availability:** The adequate resources of this article are publicly accessible.
- **Authors Contributions:** The authorship of this article is attributed equally to all participating authors.

REFERENCES

1. Load frequency control strategies: A state-of-the-art survey for the researcher. Shayeghi, HASH and Shayanfar, HA and Jalili, A. 2009, Energy Conversion and management, pp. 344--353. https://doi.org/10.1016/j.enconman.2008.09.014
2. Primary and secondary frequency control in an autonomous microgrid supported by a load-shedding strategy. Raghami, Alireza and Ameli, Mohammad Taghi and Hamzeh, Mohsen. s.l. : IEEE, 2013. 4th Annual International power electronics, Drive systems and Technologies Conference. pp. 282--287.
3. Fundamentals of load frequency control in power system. Mishraa, Dillip Kumar and Lia, Li and Zhangb, Jiangfeng and Hossaina, Md Jahangir. 2013, Power System Frequency Control: Modeling and Advances, p. 1.
4. Limitations and countermeasures of PID controllers. Sung, Su Whan and Lee, In-Beum. 1996, Industrial \& engineering chemistry research, pp. 2596--2610. https://doi.org/10.1021/ie960090+
5. Jager, Rene. Fuzzy logic in control. s.l. : Rene Jager, 1995.
6. Ross, Timothy J. Fuzzy logic with engineering applications. s.l. : John Wiley \& Sons, 2009.
7. Dynamic Response of Multi Area Load Frequency Control through Different Computational Techniques. Dhamanda, A and Dutt, A. 2022, Indian Journal of Science and Technology, pp. 1264--1273. https://doi.org/10.17485/IJST/v15i25.155
8. Yen, John. Fuzzy logic: intelligence, control, and information. s.l. : Pearson Education India, 1999.
9. Load frequency control strategies: A state-of-the-art survey for the researcher. Shayeghi, HASH and Shayanfar, HA and Jalili, A. 2009, Energy Conversion and management, pp. 344--353. https://doi.org/10.1016/j.enconman.2008.09.014
10. Primary and secondary frequency control in an autonomous microgrid supported by a load-shedding strategy. Raghami, Alireza and Ameli, Mohammad Taghi and Hamzeh, Mohsen. s.l. : IEEE, 2013. 4th Annual International power electronics, Drive systems and Technologies Conference. pp. 282--287.

Retrieval Number: 100.1/ijese.F451113060824
DOI: 10.35940/ijese.F4511.12100924
Journal Website: www.ijese.org

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

11. Fundamentals of load frequency control in power system. Mishraa, Dillip Kumar and Lia, Li and Zhangb, Jiangfeng and Hossaina, Md Jahangir. 2013, Power System Frequency Control: Modeling and Advances, p. 1.
12. Limitations and countermeasures of PID controllers. Sung, Su Whan and Lee, In-Beum. 1996, Industrial \& engineering chemistry research, pp. 2596--2610. https://doi.org/10.1021/ie960090+
13. Jager, Rene. Fuzzy logic in control. s.l. : Rene Jager, 1995.
14. Ross, Timothy J. Fuzzy logic with engineering applications. s.l. : John Wiley \& Sons, 2009.
15. Dynamic Response of Multi Area Load Frequency Control through Different Computational Techniques. Dhamanda, A and Dutt, A. 2022, Indian Journal of Science and Technology, pp. 1264--1273. https://doi.org/10.17485/IJST/v15i25.155
16. Yen, John. Fuzzy logic: intelligence, control, and information. s.l. : Pearson Education India, 1999.
17. S.Ravi kumar, R.P Das, A.Sampath Dakshina Murthy, K.Sunil kumar, Fuzzy Logic Based Trajectory Tracking Controller. (2019). In International Journal of Innovative Technology and Exploring Engineering (Vol. 8, Issue 6S4, pp. 1250–1253). https://doi.org/10.35940/ijitee.f1256.0486s419
18. K.Kavitha, R.Muruganandham, J.Dinesh, A.Mohammed Raheel Basha, An Efficeint Operations Management Strategy using Fuzzy Logic Decision Making Based Shop Floor Control Technique. (2019). In International Journal of Recent Technology and Engineering (Vol. 8, Issue 2S4, pp. 629–631). https://doi.org/10.35940/ijrte.b1125.0782s419
19. Usman, H., & Magaji, N. (2023). Interval Type - 2 Fuzzy Logic Controller Based Shunt Active Power Filter for Power Quality Enhencement. In International Journal of Engineering and Advanced Technology (Vol. 13, Issue 1, pp. 68–73). https://doi.org/10.35940/ijeat.a4299.1013123
20. Hassan, M. O., & Alajab, I. S. (2022). Sudan National Grid Contingency Ranking Through Fuzzy Logic Approach. In International Journal of Advanced Engineering and Nano Technology (Vol. 9, Issue 4, pp. 1–7). https://doi.org/10.35940/ijaent.c0468.049422
21. Aditya Vishwakarma, R. S. Mandloi, Enhancement of Electrical Power Quality for Three phase AC System using fuzzy Logic Based Active Power Filter. (2020). In International Journal of Innovative Science and Modern Engineering (Vol. 6, Issue 11, pp. 1–6). https://doi.org/10.35940/ijisme.i1257.1161120

Appendix

D(PU/HZ)	H(PU S)	R(HZ/PU)	T_g(S)	T_t(S)
0.015	0.08335	3.00	0.08	0.4

AUTHORS PROFILE

Dr. Nipan Kumar Das received his B.E. (Bachelor of Engineering) degree in Electrical Engineering from Assam Engineering College (Guwahati University), Assam in 1991 his M.E. (Master of Engineering) degree in Instrumentation & Control from Jorhat Engineering College(Dibrugarh University), Assam in 2015, and PhD from Dibrugarh University, Assam. He is now an assistant professor at the Department of Electrical Engineering, Jorhat Engineering College, Jorhat, Assam (Assam Science and Technology University). His areas of interest include load frequency control, adaptive controllers, fuzzy logic control, etc.

Aditya Ranjan Buragohain was born in Assam in 1999. He received his B.Tech.(Bachelor of Technology) degree in Electrical Engineering from Jorhat Engineering College (Assam Science and Technology University), Assam in 2022, and He is currently pursuing his M. Tech (Master of Technology) degree in Instrumentation & Control from Jorhat Engineering College(Assam Science and Technology University). His area of interest includes power system, load frequency control, MATLAB software, fuzzy logic control, etc.