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Application of Intelligent controller For Load Frequency Control for Multi-Area Multi-Source Power System

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Abstract

Objectives: This paper demonstrates the application of an artificial intelligence (AI) based controller for load frequency control for a two-area multi-source interconnected power system. Fuzzy PID controller parameters area Tuned using Artificial BEE colony (ABC) algorithm. The FLC-PID performance is simulated and verified using MATLAB. **Method:** For evaluating LFC Problem two different systems are considered. The first system consists of four units of the non-reheat thermal power system. The analysis is further extended by adding a hydropower plant unit with a non-reheat thermal unit. A perturbation of 0.01 P.U in step load form is considered for each area for the automatic generation control (AGC) study. **Finding:** The suggested controller Fuzzy-PID robustness is observed by varying operating loading conditions and plant parameters for a wide range. The variation in time constant (seconds) of system parameters is carried out in a range of +75% to -75%. The objective is to improve the steady-state error of the tie-line power deviation and frequency variation of an interlinked power plant. By the suggested approach, the variation in frequency and tie-line power is minimized to a great extent. **Novelty:** Artificial BEE colony (ABC) algorithm is effective. The performance of the adapted controller is compared with the previously published tuned PID controller based on Settling Time (ST) and ITAE Error. The proposed controller shows superiority. It is observed that the proposed technique can handle abrupt amplification of load (PU) and variation in system parameters like the governor, and turbine time constant. Eigenvalue analysis is also carried out. The result of the Fuzzy-PID controller is also compared with the proposed-FOPID and Proposed-ANFIS controller. The parameter of fractional order is also optimized by the ABC algorithm. For simulation, MATLAB 2016 @ Version is taken.

Keywords: Fuzzy Logic Control (FLC); Automatic Control Error (ACE); Fractional Order PID (FOPID); Adaptive NeuroFuzzy Logic Controller (ANFIS); Artificial BEE Colony (ABC); MultiSource MultiArea System (MSMAS)

1 Introduction

In modern power system operation and design of Load Frequency Control (LFC) plays a critical role in retaining the stability and reliability of an electric grid. It is important to maintain a continual balance between generation and consumption. Uncontrolled frequency deviation results in instability, outages, and equipment damage. LFC assists in maintaining steady frequency and power supply through Tie-Line. LFC supports in reducing deviations in output responses of power system (PS), which allows smoother and more reliable power distribution. Many generating units in a power system (PS) are coupled through a tie-lines; achieving a synchronism between these generating units is very difficult undertaking. An interconnected power plant means, several areas linked to each other through Tie-line. With time the complexity of the PS and its size is increasing simultaneously with the increment in power demand. To robust, the operation of the inter-related power system intelligent controlled techniques are required [(1)]. The purpose of an intelligent controller is to minimize the Automatic control Error (ACE). The ACE is equal to the product of frequency deviation and biasing factor added with power deviation, this ACE is applied as a input to the proposed controller, and the output of this controller is given to the governor of the system as an input [(2)]. The suggested controller minimizes the ACE error. With innovations in technology, the conventional controller is replaced by an intelligent controller for having a fast and better dynamic response to AGC problems.

A detailed literature review on LFC is described. Adaptive neural network (ANN) controller for hydro thermal power plant is suggested and its implementation for improving ACE is given in [(3)], Fuzzy logic controller (FLC) effectiveness for Interconnected Power system (IPS) having multi-source such has hydro, gas and thermal are illustrated in [(4)]. Hybrid GSA-PSO Technique is proposed for tuning the gain of PID controller applied for AGC in Interconnected Power Systems having Constant Generation Rate constraints (GRC) is demonstrated in [(5)]. Parameters of PID controllers K_p, K_I, K_d optimized by a newly developed artificial gorilla troops optimizer (GTO) for obtaining a desirable output, PS having wind and diesel generating units is given in [(6)] algorithms are studied and used for getting optimal results which are explored for LFC study.optimal hybrid Firefly Algorithm and Pattern Search (HFA-PS) Procedure for Automatic Generation Control (AGC) of multi-area power systems with Generation Rate Constraint (GRC) is suggested in [(7)]. Application of a nature-inspired bat-optimized technique for setting PID controller parameters to reduce steady-state error of non-reheat MAMS-IPS output response is recommended in [(8)]. GWFO algorithm for optimizing PI/PID controller for LFC study having two and three area non reheat interconnected power system is demonstrated in [(9)]. The gain of PID and Fuzzy-is optimized by employing novel Teaching-Learning based optimization techniques for MAMS-IPS having non reheat turbine is demonstrated in [(10)].

In these literatures, a single source two area system is examined for Load Frequency control study [(5,11,12)]. In this article the analysis is enhanced and refined by taking into account more than one source in each related area. As a result of this the complexity of the system is increased. To manage this complex power system network, the proposed controller is fairly effective. In these recent publications Load variation and changes in the governor and turbine time constants are not taken into account [(12–14)]. In this proposed article, the robustness of the suggested controller is tested under different loading conditions and also by varying the system parameters. In these papers, eigenvalue analysis is not used to test the system's stability [(5,11–14)]. However, eigenvalue analysis is done in the presented study for verifying the stability of the suggested system. Three different optimization approaches are studied in this presented work to evaluate the effectiveness of intelligent-controllers for LFC having MAMS-IPS. Suggested controller result is compared with different optimization technique published in literature on the basis of ITAE and settling time. These are the Following optimization techniques such as TLBO-PID [(10)], TLBO-FPID [(10)], ASOS-PID [(15)], SOS-PID [(15)] applied for the same system-1. In comparison to this control approach, the proposed controller produces better results. Different optimization technic given in literature such as BFOA-PID [(7)], GWO-PID [(9)], EPSDE-PID [(9)], CL-PSO-PID [(9)], ACO-PID [(14)], GA-PID [(16)], are explored for the system-2. This optimal controller of published work is compared with the intelligent controller proposed in this article. The proposed controller shows superiority over the different optimal controller tuned with various optimized technique illustrated in [(5,7,9,14,16)] . The outcome of the suggested controller based on ITAE and settling time is compared with the published literature.

This whole article is divided into 4 sections. Section-1 shows an introduction to LFC and explains the literature review and research gap. Section-2 illustrates Methodology for LFC study. Section-2.1 objective function, Section-2.2 demonstrates about ABC algorithm, and objective functions used to minimize ACE. Section-2.3 gives an idea about the FOPID controller, and its parameters. 2.5 Explain about proposed Fuzzy Logic Controller (FLC) and its truth table. Section - 2.5 shows an explanation of the proposed ANFIS controller with its internal structure. Section-3 demonstrates the result of both the system based on frequency and Tie-line power deviation. Section-4 illustrates the conclusion and future work followed by references.

2 Methodology

In this for load frequency control analysis, two different systems are demonstrated for LFC. One system is shown in Figure 6, having two units of a non-reheat thermal unit in both areas of the interlinked power system (PS). The transfer function model for system-1 is illustrated in[10]. The complexity of other systems is increased by adding a hydro unit with a thermal unit. The multi-area multi-source having a thermal hydro unit for each area is shown in Figure 17. The transfer function model for system-2 is illustrated in[7]. Each area is subjected to step load perturbation. Each area of the power plant is connected through Tie-line for improving system reliability and stability. For the first system, area-1 has a participation factor equal to a_{11}, a_{12} and for area-2 participation factor is equal to a_{21}, a_{22} the participation factor total for each area is equal to one. A step load Disturbance of 1% (0.01 P.U) is applied to both areas. The dynamic performance of the system is improved by the suggested controller by minimization of the steady-state error of frequency response and Tie line power deviation. Another PS shown in Figure 17, having two areas operating at 1000 MW at 50 Hz, the system is modeled using MATLAB for this operational condition. Mathematical equation for the proposed area considered from these references in[7]. Goal of this article is to justify the application of intelligent controllers For LFC. Suggested controllers are implemented for two different Power systems.

2.1 Objective Function

In this method FLC-PID parameters ($K_P, K_I and K_d$) are optimized by using Artificial Bee colony (ABC) a nature inspired algorithm. The objective of this optimization is to minimize the Automatic control Error (ACE) associated with deviation of frequency and Tie-line power. An objective function is defined which represents the ITAE of the system shown by equation (1). The values of the PID parameters are picked in such a way that this objective function is reduced. This process is fundamentally a search for the best set of PID parameter values that will lead to the finest possible performance of the system. Fuzzy-PID controller and FO-PID parameters are optimized using equation (1). Optimized gain of both controllers is illustrated in Table 1.

$$\text{Minimize ITAE } = \int_0^t \left(\left(\sum_{i=1}^{n_a} |\Delta F_i + \Delta P_{ti\ e,i}| \right) \cdot t \right) dt \tag{1}$$

ΔF_i shows the frequency deviation of the i^{th} area and $\Delta P_{\text{tie },i}$represents the power Deviation of the i^{th} interconnected area. $n_a$represent the Number of interconnected areas. Simulated Time is given by t. Constraints of the PID controller are represented by equation (2).

$$\begin{pmatrix} K_p^{\min} \le K_p \le K_p^{\max} \\ K_i^{\min} \le K_i \le K_i^{\max} \\ K_d^{\min} \le K_d \le K_d^{\max} \end{pmatrix} \tag{2}$$

2.2 Proposed Artificial Bee colony Algorithm

The Artificial Bee Colony (ABC) is an influential Mata heuristic optimization algorithm. It requires minimal control parameters, easy to use. The Intelligent behavior of honeybees is considered by this algorithm. ABC is based on a population search process. In this process, food sources represent individuals, and bees try to find the locations of food sources with high quantities of nectar. The finest solution is the food source with the uppermost nectar content[17]. Three types of bees: scouts, onlookers, and experienced bees are there in the ABC algorithm. Scout bees search for food sources without any previous knowledge of their locations. Onlookers depend on information in the form of data, obtained from other bee's waggle dances to locate food sources[18]. Experienced bees calculate the quality of food sources; remember their locations for future reference[19].

The ABC algorithm can be summarized as follows:

1. Set a population of food sources and bees
2. Employ scout bees to hunt for new food sources
3. Onlooker bees pick food sources based on the data obtained from the waggle dances of other bees
4. Experienced bees estimate the superiority of the food sources and reminisce about their locations
5. Update the population of food sources and bees based on the calculations made by the skilled bees
6. Repeat steps 2-5 until an acceptable solution is found

Overall, the ABC algorithm is an effective and efficient way to find optimal solutions to complex problems.

The objective value of i^{th} the solution is given by $F_i$several food sources are given By NF.

$$P_i = \frac{F_i}{\sum_{n=1}^{NF} F_n} \tag{3}$$

The fitness values of solutions F_n are calculated as follows by equation (10),

$$F_n = \left\{ \begin{array}{l} \frac{1}{1+F_i} i\, F_i \geq 0 \\ 1 + abs\,(\mathrm{F}_i)\, \mathrm{iff}_i \prec 0 \end{array} \right\} \tag{4}$$

The position of the food is updated based on the previous solution given by the equation (5).

$$V_{ij} = x_{ij} + \varphi_{ij}\left(x_{ij} - x_{kj}\right); j = 1,2,3,\ldots\ldots, \mathrm{D}, \text{ and } i,j = [1,2,3,\ldots\ldots.,NF] \tag{5}$$

Scaling Variable maximum and minimum values are taken between (0-5).

The output of the plant is used to compute the fitness function, which is then fed along with the approach controlling parameters as inputs to the ABC approach. The ABC algorithm is responsible for conveying the PID parameters (KP, KI, and Kd) to the intended controller, and the output of the controller is fed back to the plant. This iterative procedure continues until the deviations in frequencies and tie-line powers are reduced. The algorithmic steps of the proposed methodology incorporating ABC can be found in the Pseudo code provided in [17]. The proposed ABC algorithm setting is given as follows, colony size is 50. No iteration is 100. Variable maximum value is 10, Variable minimum value is -10.variable size for system-1 is [1,6], for system-2 it is [1,12], best cost value for system-1 is given as 0.001334. Similarly, for system-2 it is 0.000087.

2.3 Fractional Order Controller

In this paper, a supplementary controller known as the FOPID controller is used to manage and oversee the entire system. The FOPID controller utilizes non-integer differential and integral calculus and offers a broad spectrum of controlling capabilities. These capabilities are leveraged to design a highly effective controller for the system [20].

In simpler terms, when it comes to writing equations for non-integer differential and integral calculus, the commonly used method is the Riemann-Liouville (R-L) equation criterion [21,22]. The equation for the generalized transfer of the projected controller is expressed by Equation (6),

$$TF_{FOPID} = K_p + \frac{K_I}{s^{\alpha}} + K_d s^{\mu} \tag{6}$$

The statement is referring to a FOPID (Fractional Order Proportional-Integral-Derivative) controller, which has three parameters called $K_p, K_i, and K_d$ that determine its proportional, integral, and derivative gains. Additionally, there are two more parameters, μ and α, which represent the non-integer order of the differentiator and the integer order of the controller, respectively. To ensure effective and improved control action, it is recommended to optimize the controller parameters using an optimization algorithm. ABC algorithm is provided to optimize the Parameters of the FO-PID controller. Figure 1 shows the internal structure of the Fractional order PID controller.

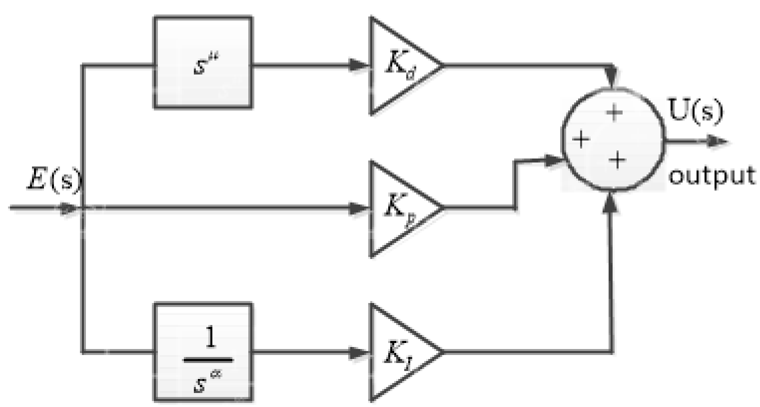

Fig 1. FOPID controller internal structure

Table 1. Tuned parameters of proposed controller optimized By ABC algorithm for power system

Proposed controller parameters	Fuzzy-PID value System-1		Fuzzy-PID value Sytem-2		Proposed controller parameters	FOPID values System-1		FOPID values System-2	
	Area-1	Area-2	Area-1	Area-2		Area-1	Area-2	Area-1	Area-2
K_p	1.9949	2.3149	1.3641	1.1.3386	K_p	2.4394	1.0664	1.2589	1.3839
K_i	2.8355	1.5181	3.1492	3.7087	K_i	3.0001	0.8152	3.0503	3.0811
K_d	2.1495	2.6869	3.6111	1.0848	K_d	1.4277	1.7304	3.8020	4.2307
					l_m	0.8303	2.8103	1.3604	1.3901
					m_u	1.2140	1.326	2.9513	3.041

2.4 Fuzzy Logic Controller

Fuzzy logic (FL) is considered a thought process or having a control methodology integrated with control system engineering (CSE) for solving a specific problem. When mathematical models are not there FLC shows the better result, when input is imprecise. FLC is knowledge-based controllers generally obtained by a knowledge-gaining process or synthesized without human intervention from self-organization control architectures[(23)]. The FL concept was given by Zadeh (1965) , a fuzzy set theory required to design FLC, representing human knowledge in terms of a linguistic variable that is called fuzzy rules. The linguistic fuzzy rules derived by human operator procedures, not required any mathematical model of the system. As conventional control can work on fixed gain, and can't adjust automatically as the dynamic of the system changes, this ability is in FLC, Which shows robustness as dynamic parameter changes in the power system. In this comprehensive analysis, FLC robustness is tested by varying the load perturbation and system parameters[(4)].

Mainly there are three components of the FLC:

- Fuzzification
- Rule-based fuzzy inference
- Defuzzification

The FLC for multi-area multi-souse hydrothermal PS is shown in Figure 2. The gain of the PID controller is scheduled with the help of ABC optimization technique. The fuzzy has two inputs ACE and derivative of ACE and output is given to the governor[(24)] . Seven membership function for each input is taken and seven MF for the output of FLC. The triangular membership function is taken for the proposed controller. Trim (LN, SN, MN, Ze, LP, SP, MP) is taken for designing the controller. The input range for ACE and Derivative of ACE and output are based on open-loop response and PID controller response which are [-1 to 1], [-1.8 to 1.8], and [-1.48 to 1.48] correspondingly. The truth table for FLC is given in Table 2.

The fuzzy logic controller (FLC) Membership is shown in Figure 2.

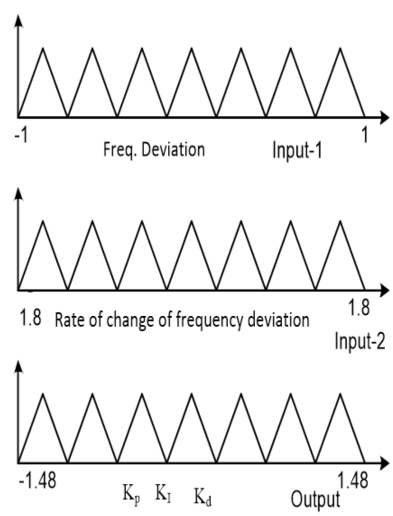

Fig 2. Membership Function For Load Frequency Control[(4)]

Table 2. Rule Base Tables for Load Frequency Control

Freq. Deviation	Rate of change of frequency deviation						
	Ln	*Mn*	*Sn*	Ze	*Lp*	*Mp*	*Sp*
Ln	*Ln*	*Ln*	*Ln*	*Mn*	*Mn*	*Sn*	Ze
Mn	*Ln*	*Ln*	*Mn*	*Mn*	*Sn*	Ze	*Lp*
Sn	*Ln*	*Mn*	*Ln*	*Sn*	Ze	*Sp*	*Mp*
Ze	*Mn*	*Mn*	*Sn*	Ze	*Sp*	*Mp*	*Mp*
Lp	*Mn*	*Sn*	*Ze*	*Sp*	*Lp*	*Mp*	*Lp*
Mp	*Sn*	*Ze*	*Sp*	*Mp*	*Mp*	*Lp*	*Lp*
Sp	*Ze*	*Sp*	*Mp*	*Mp*	*Lp*	*Lp*	*Lp*

2.5 Adaptive Neuro-Fuzzy Controller

ANFIS controller for Automatic Generation Control (AGC) is based on a Sugeno-type fuzzy inference system (FIS). This FIS can be signified in a parametric form, which allows its constituents to be tuned by neural networks. When this is done, the fuzzy system develops a neuro-fuzzy system[3]. To design the AGC controller, the inputs are the Area Control Error (ACE) and its derivative (d(ACE)/dt). The fuzzy membership functions, which depend on these variables, are used to compute the stabilizing signal that is the output of the controller. The proposed approach is executed in the Simulink environment of MATLAB, using ANFIS-Editor for system understanding. The fuzzy controller has 49 rules and 7 membership functions for each variable, which results in good performance. However, the main goal is to extract a smaller set of rules using neuro-fuzzy learning. To achieve this, the following steps are taken:

- Use neural networks to tune the parameters of the FIS
- Reduce the number of rules while maintaining the performance of the controller
- Implement the resulting neuro-fuzzy controller in the Simulink environment using ANFIS-Editor.
- The ANFIS controller for LFC is designed using MATLAB/Simulink by collecting training data, creating a FIS file with gbell MF's, training the data with the FIS, and saving the resulting ANFIS file Overall, the suggested approach offers an active method for modeling and simulating LFC. The Block Diagram of ANFIS is demonstrated in Figure 3. Detail on ANFIS-LFC is given in this literature[3].

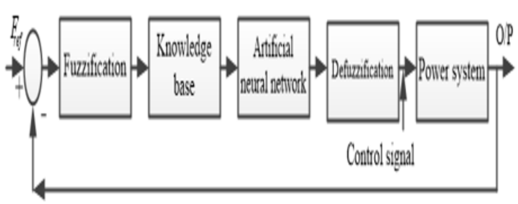

Fig 3. Block Diagram of ANFIS controller

$$Appendix - 1(System - 1)$$

$$B_1 = 20.6\text{p.}u\,; B_2 = 16.9\text{p.}u\,; T_{12} = 2$$
$$R_1 = 0.5\ \text{Hz/p.u}; R_2 = 0.6\ \text{Hz/p.u};$$
$$R_3 = 0.051\ \text{Hz/p.u}; R_4 = 0.065\ \text{Hz/p.u};$$
$$H_1 = 0.5; H_2 = 0.5; D_1 = 0.6; D_2 = 0.9;$$
$$T_{t1} = 0.5\text{sec}; T_{t2} = 0.6\text{sec}; T_{g1} = 0.2\text{sec};$$
$$T_{g2} = 0.3; a_{11} = 0.5; a_{12} = 0.5; a_{13} = 0.5$$
$$a_{14} = 0.5$$
$$Apendix - 2(System - 2)$$

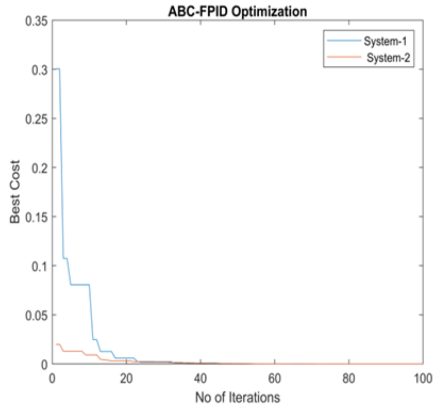

Fig 4. Number ofiterations for Artificial Bee colony (ABC) algorithm for both the systems

$f = 50$ Hz; $B_1, B_2 = 0.45 \mathrm{p} \cdot \mathrm{u} \cdot \mathrm{MW/Hz}$
$R_1 = 2.0$ Hz/p.u; $R2 = 2.4$ Hz/p.u
$T_{H1} = 0.08$sec; $T_{t1} = 0.3$sec; $K_p = 100$ Hz/pu
; $T_p = 20$sec; $K_1 = 1.0$; $T_1 = 48.7$sec;
$T_w = 1.0$sec; $T_2 = 0.513$sec; $T_R = 5.0$sec;
$T_{12} = 0.0707 \mathrm{p} \cdot u$; $a_{12} = -1$

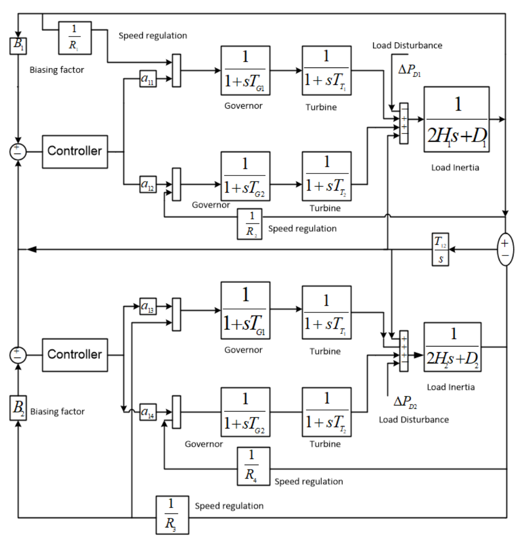

Fig 5. Block Diagram for NRHT Multi-area Multi-Sources System [10]

3 Result and Discussion

The multi-source multi-area system-1 (MSMAS) having a non-reheat thermal turbine (NRHT) and hydrothermal power system-2 (PS) are demonstrated in Figure 5 and Figure 12. The Transfer function model is simulated in MATLAB/ Simulation environment. A unit step load perturbation is applied to each area of the interrelating PS. The frequency deviation and Tie-line power deviation responses comparison is done based on ITAE performance indices and also on the basis of Settling-Time (sec). The system robustness is also absorbed by varying the load (P.U) perturbation for the wide range and also by changing the parameters of the IPS.

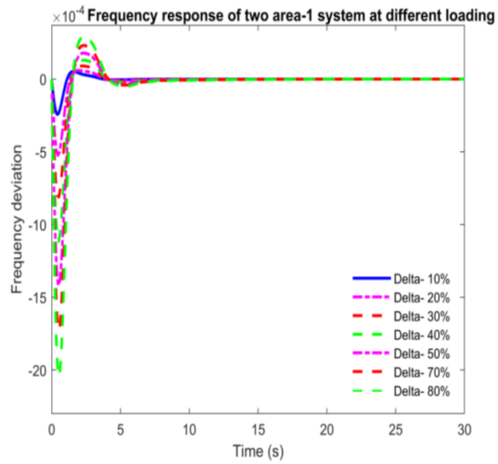

Fig 6. Proposed controller Robustness for Different Loading Conditions for area-1 for system-1

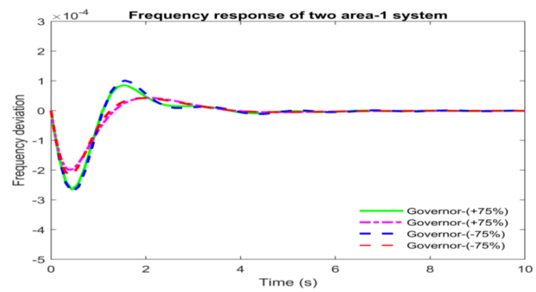

Fig 7. Frequency response for NRHT Plant for Variation in governor Time constant for area-1 of system-1

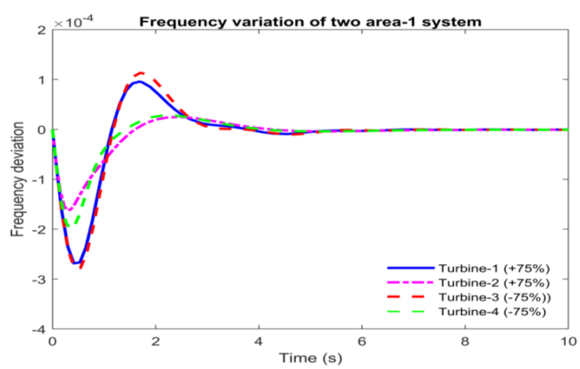

Fig 8. Frequency response for NRHT Plant for Variation in Turbine Time constant for area-1 of system-1

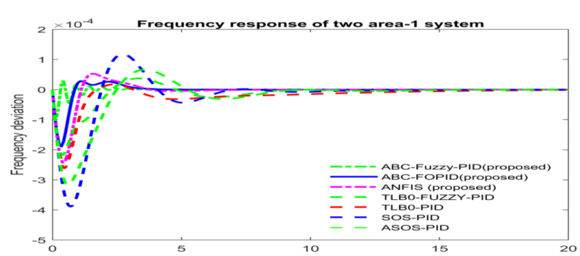

Fig 9. Proposed controller Frequency Response for Area-1 compared with Tuned PID controller [10,15]

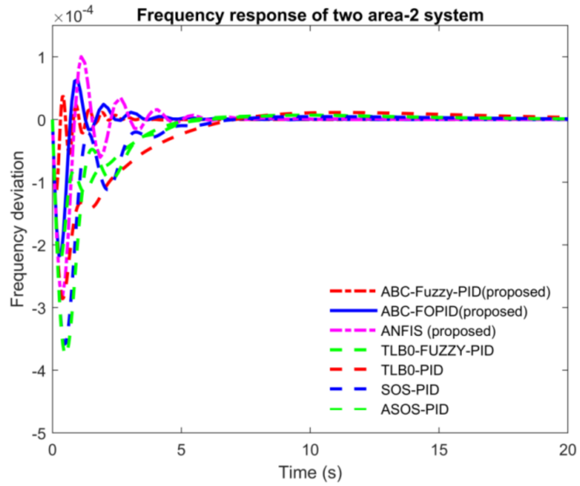

Fig 10. Proposed controller Frequency Response Deviation for Area-2 compared with Tuned PID controller [10,15]

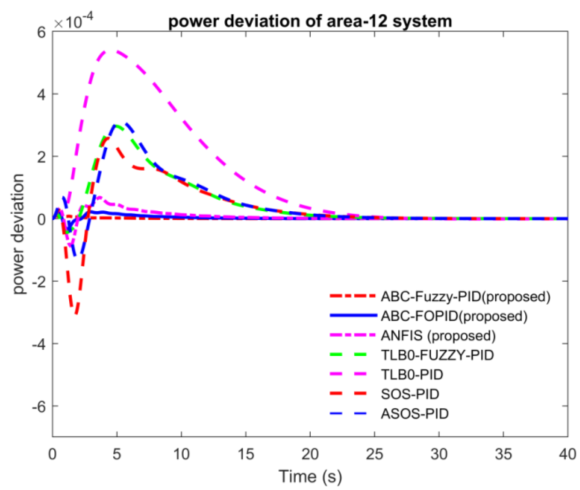

Fig 11. Suggested controller Power Response for Area-12 compared with Tuned PID controller [10,15]

Table 3. Comparative analysis of Frequency Deviation of the proposed controller with PID for system-1

S.No	Controller	ITAE Δf_1	ITAE Δf_2	ITAE ΔP_{12}	Δf_1 (sec)	Δf_2 (sec)	ΔP_{12} (sec)
1	ABC-Fuzzy- PID (Proposed)	0.0003375	0.0004498	0.002301	3.5	4	3.1
2	ABC-FOPID (Proposed)	0.0007105	0.0005901	0.004301	5	5.1	4.5
3	ANFIS (Proposed)	0.000956	0.0008901	0.009301	5.5	5.4	16.3
4	TLBO-FPID [10]	0.002038	0.001592	0.04248	10	8	18.3
5	TLBO-PID [10]	0.005172	0.00301	0.03067	12	10.2	19.8
6	ASOS-PID [15]	0.008002	0.005002	0.05011	13	10.8	20.08
7	SOS-PID [15]	0.009001	0.006810	0.07067	14.4	12.2	21.2

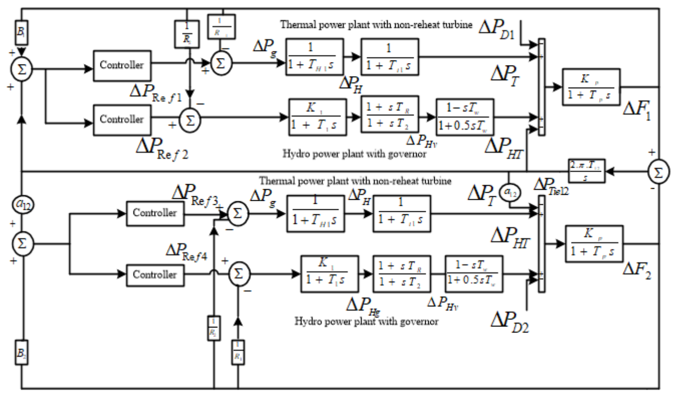

Fig 12. Transfer Function Model of MSMA hydrothermal system for LFC[7]

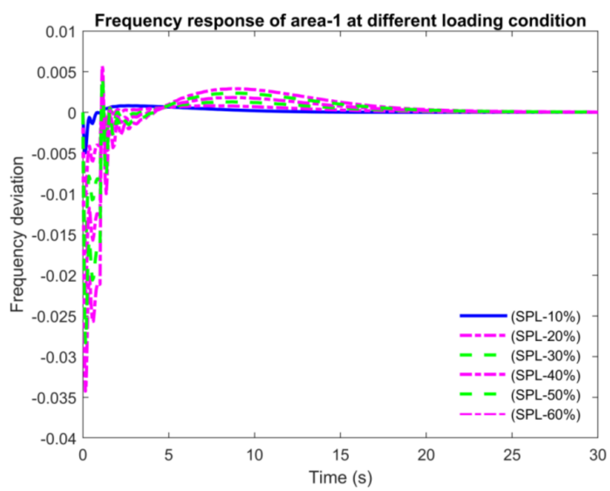

Fig 13. The frequency response of area-1 for multi-area system-2 at Different load perturbations

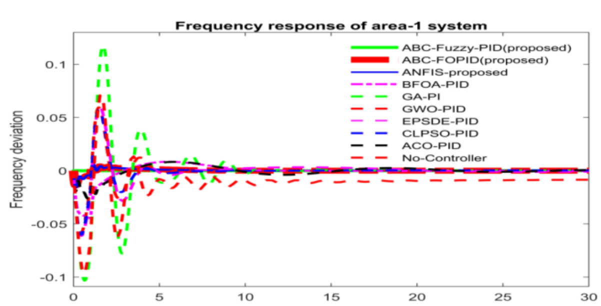

Fig 14. Frequency Deviation Response for Area-1 for MSMA system -2[7,9,14,16]

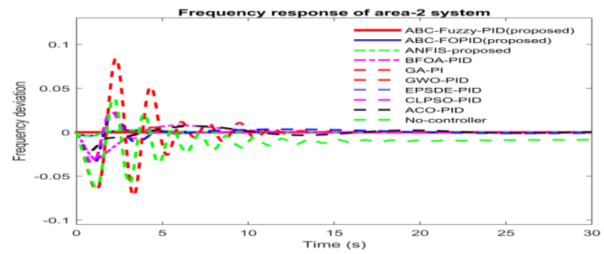

Fig 15. The frequency response of area-2 for multi-area system-2 (7,9,14,16)

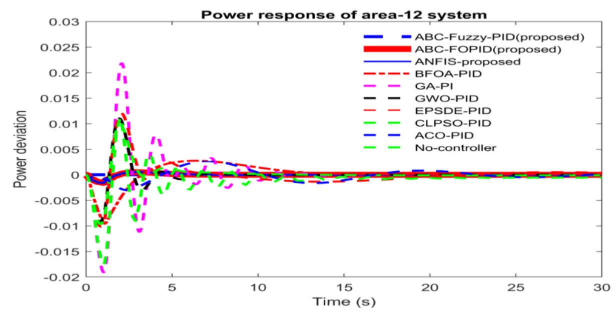

Fig 16. Critical analysis of Tie-line power Response for Area-12 (7,9,14,16)

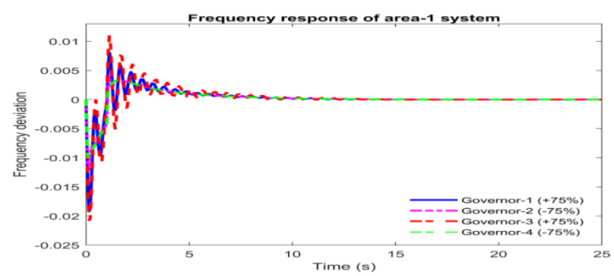

Fig 17. Frequency Response for Area-1 at different Governor Time constant

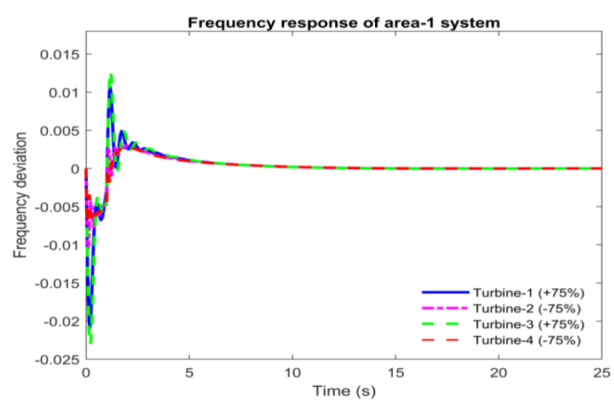

Fig 18. Frequency Deviation Response for Area-1 at different turbine Time constant

Table 4. Comparative study of Frequency Deviation of the proposed controller with PID for system-2

S.No	Controller	ITAE (Δf_1)	ITAE (Δf_2)	ITAE (ΔP_{12})	Δf_1(sec)	Δf_2(sec)	ΔP_{12}(sec)
1	ABC-Fuzzy- PID (Proposed)	0.01007	0.03208	0.01087	2.5	2.8	2.7
2	ABC-FOPID (Proposed)	0.02107	0.05036	0.04317	4.1	3.2	3.1
3	ANFIS (Proposed)	0.04001	0.07001	0.06013	4.3	3.5	3.3
4	BFOA-PID [7]	0.04887	0.08175	0.07761	7.8	7.6	11
5	GWO-PID [9]	0.06336	0.09351	0.09013	11.7	8.3	12
6	EPSDE-PID [9]	0.08007	0.09801	0.07013	12.3	12.8	13.4
7	CLPSO-PID [9]	0.09001	0.2192	0.09376	12.8	13.3	14.4
8	ACO-PID [14]	0.09801	0.2301	0.09781	13.4	15.2	15.3
9	GA-PI [16]	0.25661	0.2901	0.1091	14.1	16.2	16.9

The suggested controller robustness is verified for different loading conditions for system-1, as shown in Figure 6, similarly other area responses are taken in account. The load is varying by 10% increment. The robustness of the controlled technique is also checked by varying the parameters of the NRTS. The Time constant of the governor and Turbine are varied for a wide range from + 75% to -75% and the frequency response variation for both the area is shown in Figures 7 and 8. Figures 9, 10 and 11 shows a comparative study of the suggested controller with a PID controller Tune with different optimization natural inspired algorithm such as TLBO-FPID, TLBO-PID, ASOS-PID, SOS-PID given in cited literature. As by absorbing the output responses of the system it is clear that proposed controller response settling-Time and overshoot is minimized to a great extent near to zero. Frequency response of area-1 obtained by Suggested controller settled at 3.5 sec which is far better than the response obtained by the published literature controller. Comparative analysis of frequency response deviation and Tie-line power variation based on ITAE Error is illustrated in Table 3. As by analyzing the Table 3 it is clearly justified that Error is minimized to a great extent, as compared to TLBO-FPID controller the error is minimized by 38.8%. The demonstrated controllers ABC-FPID, ANFIS and ABC-FOPID shows a better result as compared to the tuned PID of recently published literature. Suggested FLC-PID controller effectiveness is also verified by comparing its outcome with the Proposed ANFIS and suggested ABC-FOPID controller. Tuned parameters of ABC-FPID and ABC-FOPID are given in Table 1 which is implemented for both the system-1 and system-2. The performance of the proposed controller is further evaluated by implementing it for a hydrothermal power system. Figure 13 demonstrates the toughness of the projected controller at different loading situations. The loading is incremented by 10%, 20%. The comparative analysis of the suggested controller with the recently published optimized PID controller such as BFOA-PID, GWO-PID, EPSDE-PID, CLPSO-PID, ACO-PID, GA-PID and also proposed with ANFIS and ABC-FOPOID is shown in Figures 14, 15 and 16. Frequency response obtained by ABC-FPID controller for area-1 is settled at 2.5 sec which is far better than result obtained by published PID controller. The overshoot is also minimized near to zero. The superiority of the projected Techniques is verified. The frequency response variation are shown in Figures 17 and 18 by varying the governor Time constant and Turbine Time constant from +75% to – 75 %, it is seen that the steady-state error (SSE) of the response remains unchanged as the parameters of the governor and turbine time constant is changed. Table 4 shows the comparative study of the applied controller with the optimized controller based ITAE errors and settling Time. The improvement of ITAE error is 74.3 % as compared to BFOA-PID controller.

The proposed controller performance is compared with the Tuned PID controller of the latest published journal, also with the proposed Fraction order controller and ANFIS controller. The data for both systems is provided in Appendix 1 and Appendix 2.

3.1 System analysis based on Eigenvalues

System stability can be determined through Eigenvalues. If Eigenvalues lies at the left hand of the s plane then the system is said to be stable. For both systems through the proposed ABC algorithm, Eigenvalue analysis is done. It can absorb by seeing Table 5 , that both systems are stable and all Eigenvalues located at the left-hand side of the s-plane.

4 Conclusion

This study deals with a Comprehensive analysis of ABC-FPID following with ABC-FOPID and ANFIS controller for load frequency control (LFC) of an interlinked PS. The proposed controllers are applied to the multi-area multi-source system for minimizing the SSE of the frequency variation response and power deviation to nearly zero. Without applying the controller,

Table 5. Eigen Value Evaluation for MAMS power system

S.No	Proposed ABC for system-1	Proposed ABC for system-2
1	-50.8761511162793 + 571.743734922949i	-101.624205702446 + 0.00000000000000i
2	-50.8761511162793 - 571.743734922949i	-101.614529726471 + 0.00000000000000i
3	-45.2741688353489 + 174.205820783471i	-1.27916628620351 + 12.3409439787242i
4	-45.2741688353489 - 174.205820783471i	-1.27916628620351 - 12.3409439787242i
5	-11.2314705049925 + 11.6920401589091i	-1.38751578861267 + 12.3427672506939i
6	-11.2314705049925 - 11.6920401589091i	-1.38751578861267 - 12.3427672506939i
7	-99.9999999999998 + 0.00000000000000i	-3.87938620070839 + 0.00000000000000i
8	-100.000000000000 + 0.00000000000000i	-3.88647227430973 + 0.00000000000000i
9	-8.96297842378173 + 0.00000000000000i	-0.216076116601122 + 0.00000000000000i
10	-1.18362914838040 + 2.69992816447543i	-0.980045866501939 + 1.27850113908906i
11	-1.18362914838040 - 2.69992816447543i	-0.980045866501939 - 1.27850113908906i
12	-3.78635267348720 + 0.00000000000000i	-0.980940738770297 + 1.33125840677312i
13	-2.08802259216925 + 0.00000000000000i	-0.980940738770297 - 1.33125840677312i
14	-2.29095258647023 + 0.931587537335507i	-1.84658683620288 + 0.00000000000000i
15	-2.29095258647023 - 0.931587537335507i	-1.84990578308405 + 0.00000000000000i
16	-1.19531501257063 + 0.00000000000000i	-101.624205702446 + 0.00000000000000i
17	-0.480629562911214 + 0.00000000000000i	-101.614529726471 + 0.00000000000000i
18	-0.0209695516074729 + 0.0000000000000i	-1.07916628620351 + 12.3409439787242i
19	-0.0230399677946248 + 0.0000000000000i	-1.17916628620351 - 12.3409439787242i
20	-9.91774224569297e-14+ 0.00000000000000i	-1.38751578861267 + 12.3427672506939i
21	-2.55553562369210e-13 + 0.00000000000000i	-1.38751578861267 - 12.3427672506939i

the steady-state error is very large. The proposed technique shows superiority over recently published optimization techniques. Initially, in system-1 a two-unit of NRTS is considered for each area for the AGC analysis. The proposed controller is applied to each area for reducing the Steady State Error (SSE). For testing the effectiveness of the suggested controllers the analysis is further carried out by considering a hydro-thermal unit with NRTS. As the complexity of the plant is increased by adding a new generating unit, the robustness of the suggested controller is not changed it remains as effective as it is for NRTS.

Additionally, sensitivity analysis is done by varying the parameters of the PS and also rigidness of the suggested controller is tested at Different loading situations from the normal values. The results of the proposed models are simulated in MATLAB simulation environment. A comparison of the results obtained by the suggested technique is done by the tuned PID controller and PI controller of published literature. The proposed technique gives effective results. The (ST) of the frequency response and the Tie-line power response obtained by the projected techniques is reduced. The ITAE error is minimized and satisfactory results are observed by applying the proposed approach for both the systems established for LFC study. For commenting on the stability of the proposed system Eigenvalue analysis is done in the presented article. This study can be further extended in future by incorporating more than two generating units in each area and absorbing their effect. Renewable energy sources such as wind, solar and geothermal unit can be integrated by conventional generating unit to enhance the reliability of PS. Effect of energy storage device and Fact device can also be included for improving the Tie-Line power. Novel optimization technique can be implemented for optimizing the controller parameters. Expect the PID controller mainly cascaded PID controller can be implemented and performance of LFC can be improved.

References

1) Ranjan M, Shankar R. A literature survey on load frequency control considering renewable energy integration in power system: Recent trends and future prospects. *Journal of Energy Storage*. 2022;45(1):103717. Available from: https://doi.org/10.1016/j.est.2021.103717.
2) Ramesh M, Yadav AK, Pathak PK. An extensive review on load frequency control of solar-wind based hybrid renewable energy systems. 2021. Available from: https://doi:10.1080/15567036.2021.1931564.
3) Sharma D. Automatic generation control of multi source interconnected power system using adaptive neuro-fuzzy inference system. *International Journal of Engineering, Science and Technology*. 2020;12(3):66–80. Available from: https://doi.org/10.4314/ijest.v12i3.7.
4) Ahmadi S, Talami SH, Sahnesaraie MA, Dini F, Tahernejadjozam B, Ashgevari Y. FUZZY aided PID controller is optimized by GA algorithm for Load Frequency Control of Multi-Source Power Systems. *2020 IEEE 18th World Symposium on Applied Machine Intelligence and Informatics (SAMI)*. 2020.

Available from: https://doi.org/10.1109/SAMI48414.2020.9108759.

5) Dash PM, Baliarsingh A, Mohaptra SK. Application hybrid GSAPSO Technique for AGC in Inter Connected Power System with Generation Rate Constant. *WSEAS Transactions On Circuits And Systems*. 2022;20(1):271–288. Available from: https://doi.org/10.37394/23201.2021.20.31.
6) Ramesh M, Yadav AK, Pathak PK. Artificial Gorilla Troops Optimizer for Frequency Regulation of Wind Contributed Microgrid System. *Journal of Computational and Nonlinear Dynamics*. 2023;18(1):1–19. Available from: https://doi.org/10.1115/1.4056135.
7) Sahu RK, Panda S, Padhan S. A hybrid firefly algorithm and pattern search technique for automatic generation control of multi area power systems. *International Journal of Electrical Power & Energy Systems*. 2015;64(1):9–23. Available from: https://doi.org/10.1016/j.ijepes.2014.07.013.
8) Djalal MR, Kadir N. Optimal design of energy storage for load frequency control in micro hydro power plant using Bat Algorithm. *SINERGI*. 2022;26(1):7. Available from: https://doi.org/10.22441/sinergi.2022.1.002.
9) Guha D, Roy PK, Banerjee S. Load frequency control of interconnected power system using grey wolf optimization. 2015. Available from: https://doi.org/10.1016/j.swevo.2015.10.004i.
10) Nayak JR, Pati TK, Sahu BK, Kar SK. Fuzzy-PID controller optimized TLBO algorithm on automatic generation control of a two-area interconnected power system. *2015 International Conference on Circuits, Power and Computing Technologies [ICCPCT-2015]*. 2015. Available from: https://doi.org/10.1109/ICCPCT.2015.7159427.
11) Al-Nussairi M, Al-Majidi S, Mshkil A, Dakhil A, Abbod M, Al-Raweshidy H. Design of a Two-Area Automatic Generation Control Using a Single Input Fuzzy Gain Scheduling PID Controller. *International Journal of Intelligent Engineering and Systems*. 2022;15(6):443–455. Available from: https://inass.org/wp-content/uploads/2022/08/2022123140-2.pdf.
12) Rashid A, Saini S, Safiullah S, Farooq Z. System Dynamics and Frequency Regulation of a Multi-Area Power System Using an Optimal Controller. *International Journal of Innovative Research in Engineering & Management*. 2022;p. 66–72. Available from: https://doi.org/10.55524/ijirem.2022.9.3.9.
13) Gheisarnejad M, Khooban MH. Design an optimal fuzzy fractional proportional integral derivative controller with derivative filter for load frequency control in power systems. *Transactions of the Institute of Measurement and Control*. 2019;41(9):2563–2581. Available from: https://doi.org/10.1177/0142331218804309.
14) Chen G, Li Z, Zhang Z, Li S. An Improved ACO Algorithm Optimized Fuzzy PID Controller for Load Frequency Control in Multi Area Interconnected Power Systems. *IEEE Access*. 2020;8(05):6429–6447. Available from: https://doi.org/10.1109/ACCESS.2019.2960380.
15) Nayak JR, Shaw B, Sahu BK. Application of adaptive-SOS (ASOS) algorithm based interval type-2 fuzzy-PID controller with derivative filter for automatic generation control of an interconnected power system. *Engineering Science and Technology, an International Journal*. 2018;21(3):465–485. Available from: https://doi.org/10.1016/j.jestch.2018.03.010.
16) Chandrakala KRMV, Balamurugan S, Sankaranarayanan K. Variable structure fuzzy gain scheduling based load frequency controller for multi source multi area hydro thermal system. *Electrical Power and Energy Systems*. 2013;(09):375–381. Available from: https://doi.org/10.1016/j.ijepes.2013.05.009.
17) Fathy A, Kassem A, Zaki ZA. A Robust Artificial Bee Colony-Based Load Frequency Control for Hydro-Thermal Interconnected Power System. *Sustainability*. 2022;14(20):13569. Available from: https://doi.org/10.3390/su142013569.
18) Kumar NK, Gopi RS, Kuppusamy R, Nikolovski S, Teekaraman Y, Vairavasundaram I, et al. Fuzzy Logic-Based Load Frequency Control in an Island Hybrid Power System Model Using Artificial Bee Colony Optimization. *Energies*. 2022;15(6):2199–2199. Available from: https://doi.org/10.3390/en15062199.
19) Shouran M, Anayi F, Packianather M, Habil M. Load Frequency Control Based on the Bees Algorithm for the Great Britain Power System. *Designs*. 2021;5(3):50. Available from: https://doi.org/10.3390/designs5030050.
20) Mohammed AS, Dodo A. Load Frequency Control of One and Two Areas Power System Using Grasshopper Optimization Based Fractional Order PID Controller. 2023. Available from: https://ejournal.csol.or.id/index.php/csol/article/view/12/9.
21) Kumar A, Pan S. Design of fractional order PID controller for load frequency control system with communication delay. *ISA Transactions*. 2022;129(09):138–149. Available from: https://doi.org/10.1016/j.isatra.2021.12.033.
22) Ayyappan BP, R DK. Load frequency control of three area power system using optimal tuning of fractional order proportional integral derivative controller with multi objective grey wolf optimization. *Journal of Engineering Research*. 2022. Available from: https://doi.org/10.36909/jer.13689.
23) Kumar R, Sikander A. A novel load frequency control of multi area non-reheated thermal power plant using fuzzy PID cascade controller. *Sādhanā*. 2023;48(1):1–25. Available from: https://doi.org/10.1007/s12046-022-02071-2.
24) Yadav S, Namrata K, Kumar N, Samadhiya A. Fuzzy based load frequency control of power system incorporating nonlinearity. *2022 4th International Conference on Energy, Power and Environment (ICEPE)*. 2022;p. 1–6. Available from: https://doi.org/10.1109/ICEPE55035.2022.9798219.