Prototype Of Fuzzy PID Controller For Load Frequency Control Based On Hybrid Optimization Algorithm

Avula Vijay Kumar[1][a], G. Pandu Ranga Reddy[1][b]
[1]*Department of Electrical and Electronics Enineering, G. Pulliah College of Engineering. & Technology, Kurnool, Andhra Pradesh, India*

Keywords: Firefly algorithm (FA), Pattern Search, Area Control Error (ACE), Load Frequency Control (LFC), and the Integral of Time multiplied Absolute Error (ITAE) Algorithm (PSA).

Abstract: Power system consists of large networks linked together which seem to be large and complex in structure. In connection with the component some factor affects the performance of operation as well stability, the Prime aim of power system is to meet out requirement of the load demand. For reliable, secure, economic and stable operation of a power system requires certain control strategies. The Evolution of Artificial Intelligence of cognitive behaviour paved the way to obtain optimal solution for problems involving imprecise data of nature. Soft computing algorithms resembling Genetic Algorithm, particle swarm optimization, artificial neural network, were used for the optimization process. In this proposed work, the pattern search algorithm (PSA) and firefly algorithm (FA) were used to maintain the operation frequency near the standard desired value. The controller used in this proposed work is comparing the results with some existing technique. Then the sensitivity analysis is performed for various load conditions from its nominal value. The proposed work provides the better solution for handling the nonlinearity systems.

1 INTRODUCTION

In power system network the utility of Load Frequency Control is to adjust generator output power within a specify limits with respect to change in system frequency and tie-line loading. In an inter connected system with more than regions that are separately regulated in addition to frequency control, to maintain the scheduled power interchange, the generation within each area has to be control. The control of generation in accordance with variation in frequency is termed as Load Frequency Control.

Since a power grid requires Monitoring of Generation matching load demand from time to time. It is mandatory to regulate and adjust the output of generators. This power balance match is determined by measuring the system frequency. The power generation must be maintained near the sum of load demand and related losses (Elgerd, 2000). When load demand is less than generated power the frequency will increase. In contrast, when the generated power is less than load demand the frequency decreases. The main target is to maintain the frequency as constant in the predefined value in the Load Frequency Control (Santhan Kumar Ch, 2022).

Based on the operation of generating units in response to command inputs (control signals) the LFC performance is mainly dependent. The operating characteristics of generating unit depend on operating point, type of unit, fuel, and control strategy. The Area Control Error (ACE) (Ibraheem, 2005) is defined as the control signal is the power variation of the tie line which is summed up with the frequency deviation with the inclusion of the bias factor. Through supplementary feedback to the dynamic controller, tie-line flow and frequency deviation are also combined (Vijayan M, 2022). Significant changes have seen in the designs of LFC to handle with uncertainties, different load characteristics, structure change and new systems integration (Parmar KPS, 2012). In LFC synthesis the most recent progress is to deal with the using of complex, nonlinear power system models or application of

[a] https://orcid.org/0009-0000-9689-9222
[b] https://orcid.org/0000-0001-9384-0081

Vijay Kumar, A. and Ranga Reddy, G.
Prototype Of Fuzzy PID Controller For Load Frequency Control Based On Hybrid Optimization Algorithm.
DOI: 10.5220/0012506000003808

In *Proceedings of the 1st International Conference on Intelligent and Sustainable Power and Energy Systems (ISPES 2023)*, pages 38-44
ISBN: 978-989-758-689-7

modern concepts to the system such as Neural networks, Fuzzy logic, Multi agent systems, and evolutionary and Heuristic Optimization techniques (Ghoshal SP, 2004).

In literature survey, many researchers have done their works on Load Frequency controller, by using optimization techniques and tools such as, Genetic algorithm (GA), Particle Swarm optimization technique and Artificial Neural Network (ANN) etc. Each algorithm performs well for controlling the frequency (Gozde H, 2011). However every new arrived approach gives improved results than the existing methodology. Here the proposed work presents fuzzy PID controller based on the firefly algorithm and pattern search algorithm. In DE based PID controller, the DE algorithm determines the gain of PID controller whereas the PID controller performs the tuning process for controlling the load frequency (Sahu RK, 2013). Fuzzy logic controllers have the ability to analyze the non-linear systems, However it does not have any specific mathematical formulation for considering the parameters and selecting the input, output (C. N. Sai Kalyan, 2022).

The operation of the power grid is dependent on optimization methods, the controller's structure objective too. Hence it custom to aid on high performable heuristic algorithm intend to solve the real time problems obtaining optimal solutions. The Firefly algorithm is a type under the heuristic algorithms and a biologically stimulate Meta heuristic algorithm proposed by Yang. Firefly algorithm works on population search and it was stimulate by the flashing behavior of Fireflies. Firefly algorithm can solve non-linear Optimization problems in successful and efficient manner.

In the search process of firefly algorithm a balance is maintained between the exploitation and the exploration. Pattern search algorithm is being integrated along with the firefly algorithm for achieving good performance. Due to fact that firefly algorithm explore in search space may not obtain the better solution because of exploitation. The pattern search algorithm can exploit in local area search space may yield better result than firefly algorithm. Combining the features of two algorithms the best solution for the system's objective function has been arrived. In this paper, the Load Frequency Control is applicable to multi area power systems and for tuning the input and output to the PID controller the Firefly algorithm and the Pattern search algorithm were used.

2 FUZZY PID CONTROLLER

A PID controller calculated the error (a measured variable's deviation from the expected set point present on the system). The error can be reduced by the controller by rearranging the process through manipulated variable. The parameters involve in the PID controller and sometimes called three-term-control is Proportional Gain (Kp), Integral Gain (Ki) and Derivative Gain (Kd).

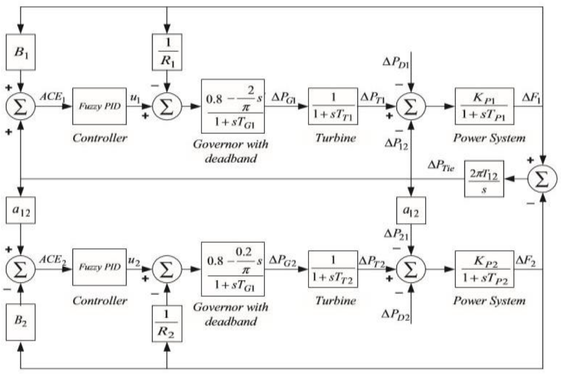

Figure 1: TF model for two area system

These parameters are defined in terms of time:

P rely on the present error, I rely on the past error collection and D is the future error forecast based on the existing rate of deviation. The process can be adjusted by weighted sum of these sections through a control element like damper and the position of a control valve.

1. Proportional gain can minimize the rise time and no effect in the steady state error.

2. Integral gain can minimize steady state error but it weakens the transient response.

3. Derivative gain will increase the system stability, reduce the overshoot and improve the transient response.

3 SYSTEM STUDY AND PROPOSED CONTROLLER

For the design and analysis purpose an interconnected two area system has taken. The rating of each thermal plant is 2000MW. Frequency bias parameters are denoted as B_1 and B_2. Area control errors for both two systems are denoted as ACE_1 and ACE_2. The controller output for system1 denoted as $u_1$and u_2 for system 2. The speed regulation of governor was denoted as$R_1$and R_2in pu Hz. Time variables are denoted called TG_1 and TG_2. Time constants for turbines are denoted asTT_1 and TT_2in sec. Change of the turbine outputis representing as DPT_1 and DPT_2. Change in load demand is representing as DPD_1 and DPD_2. The change in the tie-line power is represented as DPTie (Saikia LC, 2011). Power system gain and time constant are denoted as KP_1, KP_2andTP_1, TP_2.

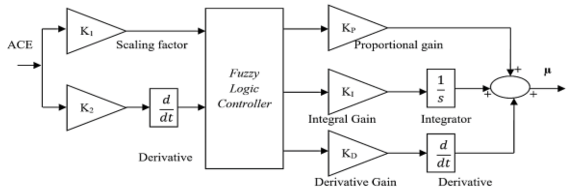

Figure 2: Structure of proposed LFC.

The speed governor dead band is a term used in speed governor, and it is very small. The non-linearity of the speed governor is solved by the speed governor dead band. Generally mechanical frictions, valve overlaps in relay are some of the factors contributing governor dead band. This dead band increases the non linearity of the system and makes the optimization problem as more complex. The proposed work mitigates the dead band's effect on power system and also improves the performance of system under consideration.

For controlling the frequency near the operating point, fuzzy PID controller has used in each area. The structure is shown in the following figure 2,

The area control error (ACE) induced by the specific error signal in each area is calculated and fed as the input.

E1(t) = B1* + ACE1(Change in frequency 1) + Change in Tie Line Power 1 (1)

E2(t) = ACE2+B2*(Change in frequency2) + Change in tie line power2 (2)

At this point, the error (E) and the first derivative of error are fed as the input signal. The fuzzy PID controller output signals are given as input signal to the power systems. Tunable parameters (K_1,K_2)are input scaling factors. K_P, K_I, K_D are the Proportional gain, Integral gain and Derivative gain. The membership function is used with three fuzzy parameters N(negative), P(positive) and Z(zero), both the input and the output are used for these. The Fuzzy Logic Controller (FLC) output is defuzzed using the Centre of Gravity approach. The rule base for Error, Derivative Error, and FLC Output is displayed in the table 1.

Table 1: Rule table for LFC.

E	Example E''		
	N	Z	P
N	N	N	Z
Z	N	Z	P
P	Z	P	P
N	N	N	Z

4 OBJECTIVE FUNCTION

Based on the concept of recent Heuristic optimization technique we can design a controller based on this work. Integral of Time multiplied Absolute Error (ITAE), Integral of Squared Error (ISE), and Integral of Time multiplied Squared Error (ITSE) and Integral of Absolute Error (IAE) are the various performance criteria for designing a controller. By using the ITAE criterion we can reduced the settling time and the peak overshoot. ITSE base controller gives larger controller output with an unexpected change in the set point occurs. However the ITAE base controller suits as the better method for Load Frequency Control, accordingly ITAE is used as the objective function for this work, for optimizing the scaling factors, K_P, K_I and $K_{D.}$

Objective function,

$$F = ITSE = \int_0^t (|\Delta F1| + |\Delta F2| + |\Delta P_{Tie}|).t.dt \quad (3)$$

The frequency change and the incremental change in the tie-line power were represented in this objective function can be given as,

Minimize F

Subject to,

$$K_{Pmin} \leq K_P \leq K_{Pmax} \quad (4)$$

$$K_{Imin} \leq K_I <= K_{Imax} \quad (5)$$

$$K_{Dmin} \leq K_D < = K_{Dmax} \quad (6)$$

This is the objective function for the proposed work. K_P, K_I and K_D are the Proportional, Integral and Derivative gain.

5 FIREFLY ALGORITHM

Firefly algorithm is a Heuristic mathematical optimization for solving the optimization problems. The algorithm works on the flashing behavior of the Fireflies. The scientific reason behind the flashing behavior of the Firefly is that it contains some organic compounds named as lucifer in. Whenever the air enters into the abdomen, it reacts with the luciferin and emits light. This luciferin is a chemical compound which emits the light. Based on this flashing behavior and with the following assumptions the firefly algorithm has derived. The assumptions are,

1. All fireflies are unisexual; they attract others and get attracted by others.
2. The brightness defines the degree of attractiveness. The brightness and distance are directly proportional to each other. The firefly is attracted by another one which has more brightness that means a nearby firefly.

3. If no other firefly has more brightness than the given one, in the search space it will move randomly.

Two factors are defined for the optimization using firefly algorithm and they are the light intensity variation and attractiveness. Attractiveness is determined using the objective function's measurement of the firefly's brightness. Brightness is the problem's objective function right now.

The light intensity is given as,

$$I(r) = I_O e^{-\gamma r} \tag{7}$$

Where,

I(r) represent the light intensity at distance r.

γ is a light absorption co efficient

The attractiveness of the firefly can be given as,

$$\beta = \beta_O e^{-\gamma r^2} \tag{8}$$

Where β_O the attractiveness at the distance r=0. Euclidean Distance is defined as the distance between two fireflies. The search space possesses 'n' no of fireflies. Every firefly participates in the optimization problem. At any instant of time, the ith firefly is attracted by jth firefly and the distance can be calculated as,

$$r_{ij} = |s_i - s_j| \tag{9}$$

rij= distance between the ith and jth firefly.

The ith firefly is in search of the jth firefly to attract it. The ith firefly moves randomly to the firefly sj which has more brightness. This searching process is done by random selection at particular time intervals. From this time it achieves the maximum no of iterations, and the best solution will be obtained by the objective function whether maximum or minimum.

The moment speed can be written as,

$$s_i = s_i + \beta_O e^{-\gamma\, rij^2}(s_j - s_i) + \alpha\varepsilon_i \tag{10}$$

Where, α is the randomization parameter,

ε_i is the random generated number.

Various steps involved in the FA algorithm is,

Step1: Generation of initial population of the fireflies.

Step2: Evaluation of fitness for all fireflies from the objective function.

Step3: Update the fitness value of firefly.

Step4: Rank and update the firefly and its position.

Step5: Check for maximum no of iteration.

Step6: Optimal result for the objective function.

6 PATTERN SEARCH ALGORITHM:

This algorithm is very Lucid and derivative-free optimization algorithm used for solving a variety of optimization problems. In some cases, it performs better than the standard optimization algorithms. The algorithm is initiated with the initial point or position. And it adds the nearby points to it to form a mesh. The initial points are added to it by the constraints. Then this current point adds the scalar multiple of a set of the vector, which is called as the pattern. The point in the mesh, which has the improved objective function, then it is marked and used as the recent point for the next iteration (Ali ES, 2011).

Initially, it chooses a point from the search space and set it as the optimum solution. Then it moves right, left, up and bottom to search the points. If the objective function is applicable for minimization problem it chooses the point which has the minimum value. Then again it searches the points around it and compares with the current optimum point. The solution obtained is less than the current point, then it moves to it and fixes it as the optimum point. This process will continue till the surround points are greater than the current optimum point. The process repeats till we turn up the optimum best solution. The initial point is set as the X and it assumed as the current optimum point. It takes the points around it and form a mesh. Then it measures the value of every point in the mesh. As shown in figure it goes for the position like, X[1,0], X[-1,0],X[0,1] and X[0,-1]. These points possesses some values belongs to it. Based on the objective function, the new optimum point has been selected. If the objective function is maximization, then the point which has the maximum value on the mesh will be taken as the new optimum point for the next iteration. If the objective function is minimization, the minimum value will be selected. This process will be repeated till get the global optimum solution.

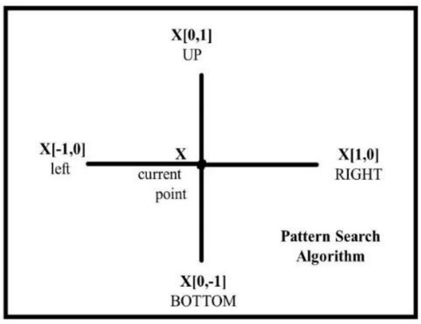

Figure 3: Pattern search algorithm.

7 HYBRIDIZATION OF FA AND PS ALGORITHM

The objective function is to minimize F (i.e. Integral of Time multiplied Absolute Error, ITAE).

The firefly algorithm is used for obtaining the initial point for Pattern Search algorithm. This current point is denoted as N. The size of mesh is 1 for the first iteration, and the pattern has formed as [1, 0], [-1, 0], [0, 1] and [0,-1]. For calculating the mesh points like, N0+[1,0], N0+[-1,0], N0+[0,1], and N0+[0,-1] for the current point these vectors are added. After computing the mesh points, the algorithm find out the objective function values. When the objective function value of N0 is greater than mesh point the iteration is successful and the new objective function is set on the.

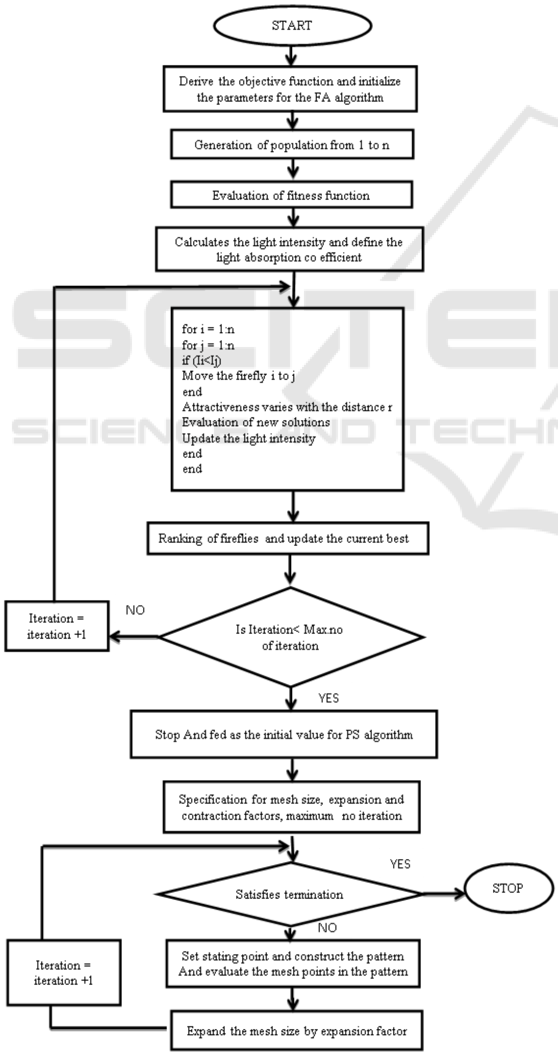

Figure 4: Flow chart of proposed algorithm.

small mesh point and named it as N1. After this first iteration the process will continue for the second iteration and the mesh size is increased to 2 and called as the expansion factor. The values of the mesh points in iteration 2 are N1+2*[1, 0], N1+2*[-1, 0], N1+2*[0, 1], and N1+2*[0, -1]. This process will be repeated until achieve the global optimum point

8 SIMULATION:

The transfer function of each area is represented as the Simulink model in the MATLAB. The fuzzy logic PID controller has designed by using the firefly algorithm and the pattern search algorithm. Fuzzy controllers are designed for each area. When applying 1% load change in the area 1 then the frequency associated with this area will disturb. The FA algorithm works on it and brings that back to its standard value. The curve has plotted for this using FA and compares with the DE and PSO fuzzy controllers' waveform. The MATLAB Simulink model is shown in figure 5.

For the optimum solution with the minimum no of iteration, the no of fireflies and maximum generation must be defined exactly. The no of iteration is directly proportional to the no of fireflies. The effect of firefly algorithm, hybrid firefly algorithm and pattern search algorithm were compared with no of iterations and the hybrid algorithm takes less no of iterations to achieve the best solution. This shows in following figures 6-9.

Table 1: PERFORMANCE COMPARISON FOR VARIOUS TECHNIQUES

S.NO	Various Optimization Techniques	Errors				Settling Time deviations		
		ISE	ITSE	ITAE	IAE	$\Delta F1$	$\Delta F2$	ΔP_{Tie1}
1.	PSO algorithm based FLC	4.38 x10^3	7.983 x103	.5782	.2075	9.674	10.957	13.158
2.	DE optimization algorithm based FLC	0.13 x10^3	0.079 x10^3	.0579	.0278	5.184	5.528	8.675
3.	FA algorithm based FLC	0.35 x10^3	0.279 x10^3	.0315	.0166	4.197	5.697	4.236
4.	New Hybrid FA & PS algorithm based FLC	0.28 x10^3	0.134 x10^3	.0126	.0124	2.289	3.859	3.009

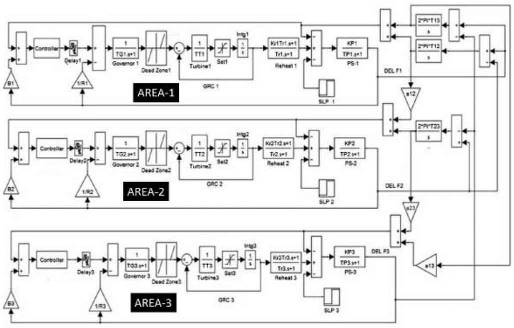

Figure 5: Simulation Model for three area system

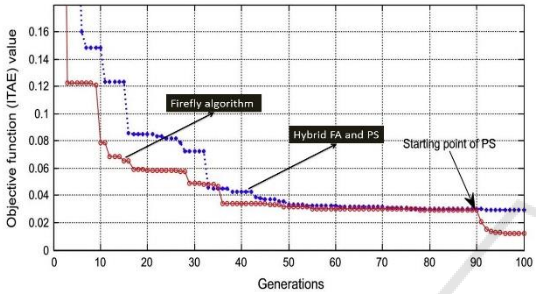

Figure 6: Convergence of FA and proposed Method

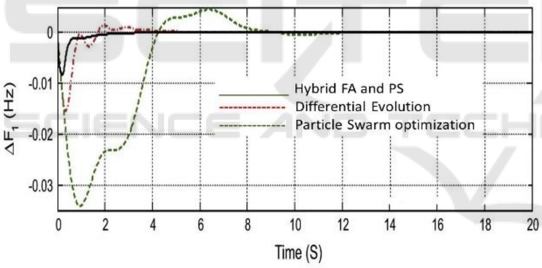

Figure 7: Frequency deviation for 1% change in area-1

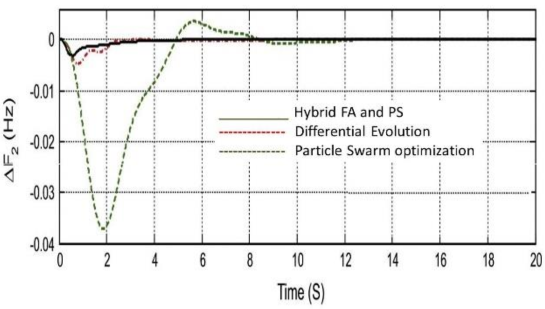

Figure 8: Frequency deviation for 1% change in area-2

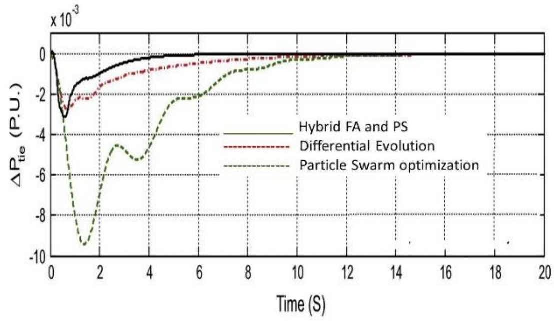

Figure 9: Tieline power deviation for 1%change area-1

9 RESULT

The performance for this submitted work is compared with the recent optimization techniques such as, Differential Evolution (DE) algorithm and Particle Swarm Optimisation (PSO) algorithm. The Firefly algorithm obtains the minimum errors for the interconnected system as compared to other techniques. The hybridization of firefly and pattern search algorithms further reduces the errors as compared to Firefly algorithm. The proposed work performs better in terms of minimum setting time, power deviations, and accuracy.

10 CONCLUSION

By integrating two optimisation algorithms, a novel optimisation technique has been suggested. The firefly and pattern search methods are both quite straightforward and successfully used. The global exploration and pattern search capabilities of the Firefly algorithm are superior for greater local exploitation. Due to reality if they are operated alone firefly algorithm is poor in local exploitation and pattern search is poor in global exploration. Incorporating the prominent attribute from these two algorithms satisfactory methodology has been obtained for best optimal solution. In this paper the comparison is made between individual FA algorithm, Particle Swarm optimization algorithm, Differential Evolution Optimization technique and hybrid FA and PS algorithm and represented. Amid this all performance the proposed hybrid approach achieves the best optimization solution.

REFERENCES

Elgerd OI. Electric energy systems theory – an introduction. 2nd ed. New Delhi: Tata McGraw Hill; 2000.

Santhan Kumar Ch, N. Karuppiah, B. Praveen Kumar, S. Shitharth, B. Dasu, "Improvement of the Resilience of a Microgrid Using Fragility Modeling and Simulation", Journal of Electrical and Computer Engineering, vol. 2022, Article ID 3074298, 12 pages, 2022. https://doi.org/10.1155/2022/3074298.

Ibraheem, Kumar P, Kothari DP. Recent philosophies of automatic generation control strategies in power systems. IEEE Trans Power Syst 2005;20:346–57.

Vijayan M, Udumula RR, Mahto T, Lokeshgupta B, Goud BS, Kalyan CNS, Balachandran PK, C D, Padmanaban S, Twala B. Optimal PI-Controller-Based Hybrid Energy Storage System in DC Microgrid. Sustainability. 2022; 14(22):14666. https://doi.org/10.3390/su142214666.

Parmar KPS, Majhi S, Kothari DP. Load frequency control of a realistic power system with multi-source power generation. Int J Elect Power Energy Syst2012;42:426–33.

Ghoshal SP. Application of GA/GA–SA based fuzzy automatic generation control of a multi area thermal generating system. ElectrPower Syst Res 2004;70:115–27.

Gozde H, Taplamacioglu MC. Automatic generation control application with craziness based particle swarm optimization in a thermal power system. IntJ Elect Power Energy Syst 2011;33:8–16.

Sahu RK, Panda S, Rout UK. DE optimized parallel 2-DOF PID controller for load frequency control of power system with governor dead-band nonlinearity. IntJ Elect Power Energy Syst 2013;49:19–33.

C. N. Sai Kalyan, B. Srikanth Goud, H. Kishan, P. Ramineni, B. P. Kumar and T. Anil Kumar, "Donkey and Smuggler Optimization Algorithm-based Degree of Freedom Controller for Stability of Two Area Power System with AC-DC Links," 2022 IEEE 7th International Conference on Recent Advances and Innovations in Engineering (ICRAIE), MANGALORE, India, 2022, pp. 461-466, doi: 10.1109/ICRAIE56454.2022.10054318.

Saikia LC, Mishra S, Sinha N, Nanda J. Automatic generation control of a multi area hydrothermal system using reinforced learning neural network controller. Int J Elect Power Energy Syst 2011;33(4):1101–8.

Ali ES, Abd-Elazim SM. Bacteria foraging optimization algorithm based load frequency controller for interconnected power system. Int J Electr Power.