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An Adaptive Controller Design using Duelist Optimization Algorithm for an Interconnected Power System

Nipan Kumar Das, Papu Moni Saikia, Mrinal Buragohain, Nikhil Saikia

Abstract: ***A Controller is generally considered as a continuous and discrete mode of execution by a huge sample period that may result in degenerated dynamic performance or system instability. Nowadays, the maximum penetration in thermal, wind, hydropower systems has decreased the power system inertia that leads to rapid frequency response and higher frequency deviation followed by contingencies and requires rapid load frequency control. The goal of load frequency control (LFC) is to achieve zero steady-state errors in frequency deviations and minimize unscheduled tie-line power flows among the interconnected areas. The study of the literature reveals that a lot of research has been carried out in this area to achieve the desired objectives using different approaches. This manuscript proposes an optimization algorithm called Duelist Optimization Algorithm (DOA) in a three area interconnected power system consisting of thermal, wind, and hydro generating systems. The proposed system introduces an adaptive PID fuzzy controller whose parameters are optimized by the DOA algorithm. The Duelist Optimization algorithm is used to optimally tune the parameters of the controller in order to keep the system frequency deviation within the threshold limit, and maintain the power balance among the control areas during load variations. The proposed method is simulated in MATLAB / Simulink environment for the estimation of its performance and then compared with some of the existing techniques such as Artificial Bee Colony (ABC) optimization algorithm, Bacteria Foraging Optimization (BFO), and Particle Swarm Optimization (PSO) algorithm. The simulation result established the suprerioty of the proposed method over the other methods.***

Keywords: Frequency Deviation, Duelist Optimization, Lfc, Adaptive Pid Fuzzy Controller, Wind Area, Thermal Area, Hydro Area.

I. INTRODUCTION

In the present world, with the increase in electric utility capacity, the number of power system interconnections is also increasing, which gives rise to a much more complex power system network.

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*Correspondence Author
Nipan Kumar Das, Assistant Professor, Department of Electrical Engineering, Jorhat Engineering College, Jorhat (Assam), India.
Papu Moni Saikia, Assistant Professor, Department of Electrical Engineering, Jorhat Engineering College, Jorhat (Assam), India.
Dr. Mrinal Buragohain, Professor, Department of Electrical Engineering, Jorhat Engineering College, Jorhat (Assam), India.
Nikhil Saikia*, M.Tech (Pursuing), Department of Electrical Engineering, Jorhat Engineering College, Jorhat (Assam), India.

Thus controlling the power system parameters has become an important aspect [1].

Therefore, the whole system is grouped into smaller control areas, and all these control areas are linked together using tie lines. In an area, the power capacity depends on its synchronous generator ratings [2]. For achieving stable and satisfactory system performance, the LFC of interrelated power systems plays an important role, while the system is affected by any issues like step load disturbances (SLPs) that are produced by any frequency change [3]. Operation of system and stability is affected by LFC control [4,5]. To overcome the issues of interconnected power systems, many control techniques like classical control, adaptive control, optimal control, robust control, etc., are introduced [6-7]. Commonly the artificial intelligence controllers are characterized by a long training period and a difficult structure [8]. Moreover, controllers like H_∞ controllers, slide mode controllers are also used to solve the problems of LFC in an interconnected power system which shows robustness against parametric uncertainties. These controllers also have some limitations, such as long calculation time and complex procedures [9]. Therefore for solving the issues of interconnected power systems, conventional optimization techniques are found suitable, but it has several drawbacks such as initial condition dependency multiple peaks of the non-linear system [10]. Hence to overcome these drawbacks the meta-heuristic optimization techniques like particle swarm optimization, whale optimization algorithm (WOA), genetic algorithm (GA), artificial bee colony algorithm, firefly algorithm (FA), cuckoo search algorithm, harmony search algorithm, water cycle algorithm, grey wolf optimization algorithm, etc. are introduced [11] to solve the problems associated with LFC. In addition to these quasi-oppositional harmony search algorithms (QOHS), differential algorithm (DE) [12-16], slap swarm algorithm (SSA), and symbiotic organisms search algorithms are the other meta-heuristic optimization algorithms that are used for solving LFC problems of interconnected power systems [17]. In recent years computational evolutionary and soft computing-based algorithms are being introduced to address the problem of interconnected power systems [18-20]. This paper proposes an optimization algorithm called the duelist optimization algorithm for fine-tuning the parameters of an adaptive PID fuzzy logic controller in a multi-area hybrid interconnected power system consisting of renewable sources and considering system nonlinearities. An adaptive PID fuzzy controller is used commonly because of its minimal cost and high margin of stability.

The objective of this manuscript is to ensure and analyze the robustness of the proposed controller based on duel optimization algorithm (DOA) and to improve the frequency deviation performance and the tie-line power exchange during a disturbance in the system. The entire manuscript is structured as: Section II gives a brief literature review of recent work, Section III describes the system modeling and design analysis, Section IV demonstrates the proper controller design, Section V explains the proposed optimization method, Section VI contains the simulations results that are obtained by comparing the proposed DOA tuned adaptive PID fuzzy controller with others methods and at last, section VII concludes the manuscript.

II. BACKGROUND OF THE RESEARCH WORK

The study of the literature shows that the power system performance depends not only on the method employed or the controller structure but also on objective function selection. Optimal functioning of the system together with robustness against the parameter change is the most significant and mandatory action of the control pattern in the power system. In addition, data drop reasons with communication failure may be converted to a time-varying equivalent system not assumed under bibliography till now [21-25]. System performance is affected by time delay, the dead band generation rate of coupling governor under power system LFC.

Recently, many optimization algorithms like SSA, FA, WOA, Grasshopper Optimization Algorithm (GOA), cuckoo optimization algorithm (COA), butterfly optimization algorithm (BOA), constrained population external optimization (CPEO) are employed to LFC control issue of an interconnected power system. SSA is used for the wide search space problems and better convergence acceleration, but it has some demerits such as probability distribution changes by generation, suffering from premature convergence, and no theoretical convergence frame.

FA is good and efficient to control the problem, and it requires small iteration, but it has a great probability of being trapped under local optima since they are local search algorithms. WOA provides control parameters, easy computation, and a strong capability for searching optimal solutions. Though, WOA has the drawback of slow convergence speed. GOA implies a state-of-art population-depend meta-heuristic algorithm used for solving numerous optimization issues under an LFC power system with good performance, but it has some demerits such as the original linear convergence parameter creating the exploration and exploitation process imbalanced, unstable convergence speed.

COA is used for solving LFC problems optimally; it is based on fewer parameters and is robust. It consists of Levi's flight trait that improves their global search capability. It is simple to combine with other algorithms, which shows great versatility. But the system performance enhancement and processing of a few links at rest require continuous optimization; the convergence rate is pretentious through Levi's flight and can be a bit slower. BOA has fast convergence rates, and hence the probability of falling in local optima is reduced. Although it has high accuracy, it has some limitations also such as poor exploitation ability, premature convergence to a local optimum. Under this work, some control methods are exhibited to solve the LFC problem; also, the computational drawbacks mentioned above have inspired to carry out this investigation.

III. SYSTEM MODELING

In this paper, a three-area interconnected hybrid renewable non-linear power system is considered. The three areas consist of a thermal, wind, and hydro system. Fig.1 displays the block diagram of the three-area renewable hybrid non-linear power system. Area 1 has a thermal superheat system run by a governor with a governor dead band (GDB), generation rate constraint (GRC) nonlinearities, and area 2 consists of a turbine with a filter and a wind energy conversion system (WECS), and area three consists of a hydro system with a (GRC) [26-28].

A. Thermal Power System Modeling

The Thermal power system comprises a generator, reheater, and turbine. The temperature and pressure of the high units are converted into mechanical energy through the turbine and generator of the thermal power system [29].

The total magnitude of sustained speed change inside the system is called the governor dead band; therefore, the valve position does not change. Dynamic performance of load frequency control system pretentious through speed regulator due to its non-linearity. The nonlinearity is articulated as

$$y = f(x, \hat{x}) \tag{1}$$

The transfer function of the governor is

$$H(g) = \frac{K_g}{T_g s + 1} \tag{2}$$

The transfer function of the reheater is

$$H(h) = \frac{K_h T_h s + 1}{T_h s + 1} \tag{3}$$

The transfer function of steam turbine is

$$H(t) = \frac{K_t}{T_t s + 1} \tag{4}$$

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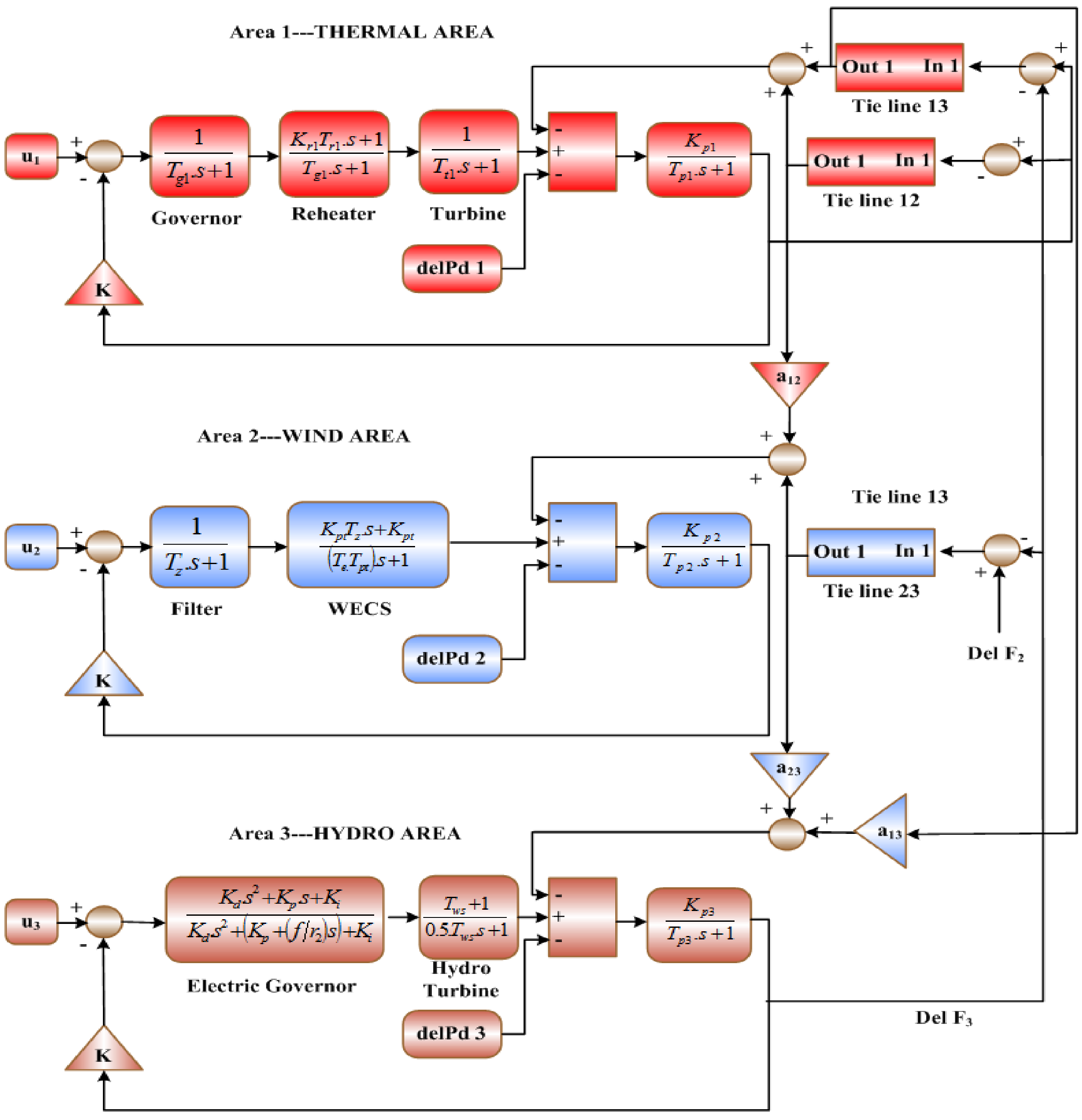

Fig.1. Three areas Thermal-Wind-Hydro power system transfer function model

B. Wind Power System

Commonly WT generated power is affected by wind speed directly.

The speed of the wind power is considered to be the sum of base ramp wind speed [30], gust wind speed as well as rapid change wind speed, noise wind speed. Speed of the wind speed is determined by,

$$V_w = V_{vb} + V_{wg} + V_{wr} + V_{wn} \tag{5}$$

The wind turbine generated power is described,

$$P = \frac{1}{2}\rho_a a D_p V_w^3 \tag{6}$$

Where, a is the turbine blade area, D_p is the air density, ρ_a is the pitch value V_w is the wind velocity.

In a wind area, a 35 MW wind power capacity system is interconnected, and the wind turbine is utilized for removing wind power from wind. Assume wind power is constant in the transfer function of wind speed. WECS second-order dynamics is achieved through the correct selection of frequency, damping factor. Two poles and WECS zero transfer function is given by:

$$H_{Pt} = \frac{K_{Pt}(T_z s+1)}{(T_\xi s+1)(T_{Pt} s+1)} \tag{7}$$

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C. Modeling of Hydro Unit

The hydropower plant is fitted by an appropriate electric governor and supplies greater performance than a mechanical governor. Kinetic energy stored under hydropower plant is turned as electricity by the support of hydro turbine and generator [31].

D. Modeling of Tie-Line and Control of Tie line

Power transfer equation via the tie line [32],

The transfer equation of power is given by

$$P_{12} = \frac{|V_1||V_2|}{x}\sin(\phi_1 - \phi_2) \tag{8}$$

Here, $V_1\ V_2$ denotes terminal voltages, $\phi_1\ \phi_2$ are the power angle of voltage, x is the tie line reactance. Consider that the power is transferred from area 1 to 2

$$P_{12} = \frac{|V_1||V_2|}{x_{12}}\sin(\phi_1 - \phi_2) \tag{9}$$

At normal operation, power in tie-line is derived as shown below

$$\left[\Delta P_{t1}(s) - \Delta P_{e1}(s) - \Delta P_{12}(s)\right] = \frac{2H_1}{f_o} s\Delta f_1(s) + b_1 \Delta f_1(s) \tag{11}$$

$$= \frac{2H_1}{f_o}\Delta f_1(s) b_1 \left[\frac{1}{b_1}s + 1\right] \tag{12}$$

$$\frac{2H_j b_j}{f_o} = \frac{1}{K_{p1}} \tag{13}$$

$$\frac{1}{b_1} = t_{p1} \tag{14}$$

Where, b_1 is the frequency bias of area1, K_{p1} is the proportional gain of area 1, $\Delta P_{e1}(s)$ is the real power load change, $\Delta P_{t1}(s)$ is the torque change power.

$$\Delta f_1(s) = g_{p1}(s)\left[\Delta P_{t1}(s) - \Delta P_{e1}(s) - \Delta P_{12}(s)\right] \tag{15}$$

$$g_{p1}(s) = \frac{K_{p1}}{1 + st_{p1}} \tag{16}$$

$$\Delta P_{12} = \Delta P_{21} = \Delta P_{31} \tag{17}$$

Where $\Delta P_{t1}(s)$ is the net surplus power of area 1, ΔP_{12} implies power change from area 1 to 2, ΔP_{21} implies power change from area 2 to 1, and ΔP_{31} implies power change from area 3 to 1.

Here, x_{12} denotes reactance of tie line from area 1 to 2. Transfer of power is in a positive direction. If small deviation under angles and tie-line power implies change by a small amount. When power is transferred from area 1 to area 2 with frequency deviation, then a change of power is provided

$$\Delta P_{12}(s) = \frac{2\pi t^o}{s}\left(\Delta f_1(s) - \Delta f_2(s)\right) \tag{10}$$

Where, $\Delta f_1(s)$ is the change of frequency in the first area, $\Delta f_2(s)$ is the change of frequency in the second area, t^o is the torque of the generator. Fig.2 shows the tie-line power of areas 1 and 2.

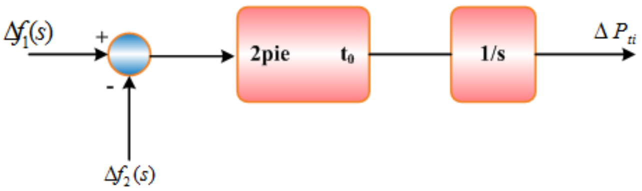

Fig.2. Tie line function of areas 1 and 2

Because of the turbine controller action, the generator increases the net output power. The system absorbs the net output power. In tie-line power flow, the steady-state error in frequency is eliminated through tie-line bias control. For the prevention of net interchange of power, the frequency control of each area must contribute. Let a_{e1} a_{e2}, and a_{e3} implies area control errors of area 1, area 2, and area 3, respectively.

$$a_{e1} = \Delta P_{12} + b_1 \Delta f_1 \tag{18}$$

$$a_{e2} = \Delta P_{21} + b_2 \Delta f_2 \tag{19}$$

$$a_{e3} = \Delta P_{31} + b_3 \Delta f_3 \tag{20}$$

Where b_1 implies area 1 frequency bias constant, b_2 implies area 2 frequency bias constant, and b_3 indicates area 3 frequency bias constant. Now ΔPr_1, ΔPr_2, and ΔPr_3 are mode integral of ACE 1, ACE 2and ACE 3 respectively.

$$\Delta \mathrm{Pr}_1 = -K_{i1}\int_0^t (\Delta P_{12} + b_1 \Delta f_1)dt \tag{21}$$

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$$\Delta \Pr_2 = -K_{i2}\int_0^t (\Delta P_{21} + b_2 \Delta f_2) dt \quad (22)$$

$$\Delta \Pr_3 = -K_{i3}\int_0^1 (\Delta P_{13} + b_3 \Delta f_3) dt \quad (23)$$

$$\Delta P_{12} = \Delta P_{ti,1}, \Delta P_{21} = \Delta P_{ti,2}, \Delta P_{31} = \Delta P_{ti,3} \quad (24)$$

Hence $\dfrac{\Delta P_{ti,1}}{\Delta P_{ti,2}} = -\dfrac{t_{12}}{t_{21}} = -\dfrac{1}{a_2} = \text{Constant}$ (25)

$$\Delta P_{ti,1} = \Delta P_{ti,2} = \Delta P_{ti,3} = 0 \quad (26)$$

$$\Delta \Pr_1 = \Delta \Pr_2 = \Delta \Pr_3, \Delta f_1 = \Delta f_2 = \Delta f_3 = 0 \quad (27)$$

The power and frequency of the tie line of every area become zero in steady-state circumstances. Integration of control area error under feedback loops of every area is used to achieve the steady-state.

IV. CONTROLLER SYSTEM

During the load disturbance, the system response produces damping oscillation and steady-state error. To overcome this issue, a controller is introduced in the feedback control system, which reduces the error signal and provides the best control action.

In the beginning, the controller under the feedback control system changes the error signal and gives the best control action [33]. Moreover, a controller is employed to change the transient response and steady-state operation of the system. In this manuscript, an adaptive PI fuzzy controller is proposed to modify the error signal and to improve the system loop gain.

The controller improves overall system performance, and the integral controller decreases the steady-state error.

A. Adaptive Fuzzy PID (AFPID) Control

A fuzzy logic controller (FLC) consists of predefined control rules on which the knowledge and experience of the investigation are based. The input of the fuzzy is processed, and the output is the t linguistic variables of membership function (MF) that is prearranged in FLC. It depends on the scaling factor and the parameter selection of the FLC controller. The unbounded effect of the control action, the scaling factor tuning is an important aspect. FLC membership function is the error and error change as input to output FLC mapping uses a minimum number of if-then rules. The static values of the scaling factor and membership function do not satisfy the control action. Hence to overcome the issue, adaptive control is used in the LFC [34]. An adaptive controller generally provides two types of control action, such as self-adjust regulators and model reference control systems. For less sensitive parameter uncertainties in several operating and environmental conditions, the adaptive controller controls the system. Fuzzy-dependent adaptive PID controller design has been assumed in this manuscript. In the proposed technique, an adaptive PID and FLC (AFPID) is employed for controlling the process optimally depending on "e" and "Δe". Fig.3 shows the proposed AFPID controller schematic diagram.

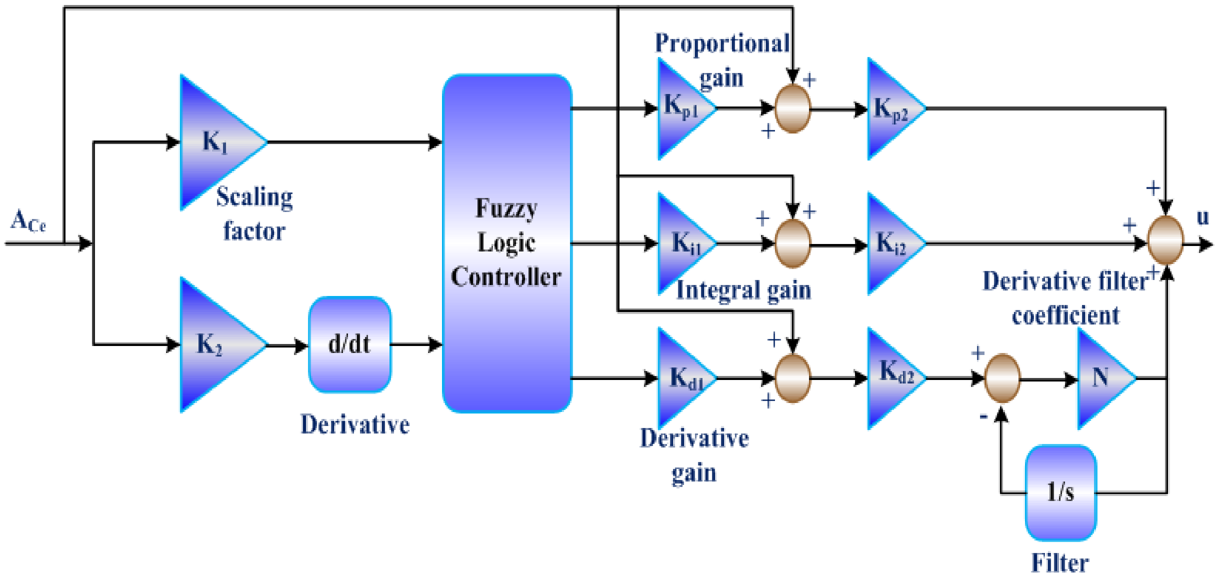

Fig.3. The Proposed AFPID controller

$$j = \int_0^{t_{max}} \left[(\Delta f)^2 + (\Delta u)^2 / K_f \right] dt \quad (28)$$

Here, t_{max} implies the maximal simulation time, Δf is the frequency deviation Δu indicates the controller output, K_f denotes the constant scaling factor. Constant factors give the control in both control areas for equal weight.

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V. OPTIMIZATION USING DUELIST ALGORITHM

The fight between two persons or among a group of persons with one another can be termed as duel. Normally, the fighting requires intellectual as well as physical potency and skill for better performance. For example, the game of chess needs more intellectual potency than physical. The widespread form of duel that comprises the physical potency is boxing; boxing is a well-known sport where two persons are required to thump down each other pertaining to some regulations. Each duel contains the loser and winner as well as the regulations.

Based on the skill, potency, and luck the competitors can become the champion. After the match, knowing the abilities of the loser and the winner are also very helpful. The loser can learn from the champion and the champion can develop the ability and expertise from the loser. In the proposed calculation, every duelist performs likewise to be phenomenal, via updating themselves whether by gaining from their rival or building up another method or expertise [35]. The Duelist Algorithm (DA) denotes a new stochastic optimization algorithm that is motivated by human learning potentials and fighting. In DA, the population character is well-known as a duelist.

For finding out the loser, winner, and champion, the duelist will fight among each other. The consequence of the combat, either lose or win will verify what type of action will be carried via the duelist.

A. Step by Step Process of Duelist Optimization Algorithm for Solving LFC Problem

Step 1: Initialization

Initialize the state vector $A=[x_1, x_2, \;\ldots\; x_n]$, disturbance vector $B=[x_1, x_2, \;\ldots\; x_n]$, and control vector $D=[d_1, d_2, \;\ldots\; d_n]$ of the interconnected power system.

Step 2: *Random Generation*

Initialize the Duelist optimization $X_i \;\; for \; i=1,2,3,\ldots,n$. In the proposed work, system data gain parameters $K_p \; K_i$ are taken as inputs which are generated arbitrarily by following matrix B:

$$B=\begin{bmatrix} K_p^{11}(t)K_p^{11}(t) & K_p^{12}(t)K_p^{12}(t) & \ldots & K_p^{1n}(t)K_p^{1n}(t) \\ K_p^{21}(t)K_p^{21}(t) & K_p^{22}(t)K_p^{22}(t) & \ldots & K_p^{2n}(t)K_p^{2n}(t) \\ \vdots & \vdots & \vdots & \vdots \\ K_p^{m1}(t)K_p^{m1}(t) & K_p^{m2}(t)K_p^{m2}(t) & \ldots & K_p^{mn}(t)K_p^{mn}(t) \end{bmatrix} \quad (29)$$

Step 3: Fitness Function

Depending on the initial position values, the fitness of each area frequency is computed, which are as follows,

$$F_t=\begin{bmatrix} f_1[(K_p^{11}(t)K_p^{11}(t) & K_p^{12}(t)K_p^{12}(t) & \ldots & K_p^{1n}(t)K_p^{1n}(t))] \\ f_2[(K_p^{21}(t)K_p^{21}(t) & K_p^{22}(t)K_p^{22}(t) & \ldots & K_p^{2n}(t)K_p^{2n}(t))] \\ \vdots & \vdots & \vdots & \vdots \\ f_n[(K_p^{m1}(t)K_p^{m1}(t) & K_p^{m2}(t)K_p^{m2}(t) & \ldots & K_p^{mn}(t)K_p^{mn}(t))] \end{bmatrix} \quad (30)$$

The objective function is represented in an optimization problem by minimizing frequency deviation by optimal tuning of the adaptive controller using duelist optimization. The objective function

$$j=\int_0^\infty t\left(|\Delta f_1|+|\Delta f_2|+|\Delta f_3|+|\Delta P_{ti}|\right)dt \quad (31)$$

$$Obj\,F_j = Min\; K_p\,, K_i$$

Δf Implies frequency change and ΔP_{ti} implies tie power change

Step 4: Registration

In this step, every duelist is registered by a binary array that is also called a skill set under DA.

Step 5:Pre-Qualification

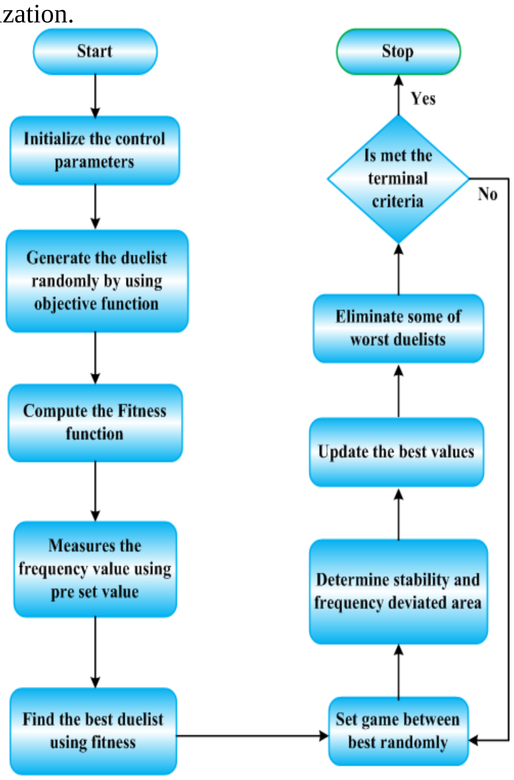
In the pre-qualification testing, the power system depends on frequency, and measures are taken that depend on the skill set on which it was determined.

Step 6: Determination of Board of Champions

The best value is taken from the pre-qualification depending on the fitness function, and others are trained to depend on its abilities. Novel duelists by equal capability are joined in the vector.

Step 7: Duel between each duelist

For every duelist, the fighting game is arbitrarily set. The winner and loser of each match are resolute from duelist abilities and luck. Duelist luck is purely determined through random functions. This should be kept away from local optimization.



(a) (30)

(b)

Fig.4. Duelist Optimization Algorithm (a) Flow chart (b) Classification

Step 8: Improvement by Duelist

After fighting, the duelists try to improve themselves and take three types of action. From the winner, the loser learns through copying the winner binary array. Learning something new and randomly producing array by the winner and new duelist trained by winner.

Step 9: Elimination

The elimination of duelists is based on capability. The worst duelist gets eliminated.

Step 10: Termination

If the stopping criterion is not met, then the process is repeated from step 7 until the best result is obtained. Fig.4 (a) shows the flowchart of the proposed duelist algorithm, and Fig. 4(b) shows the classification of DOA.

VI. RESULTS AND DISCUSSION

To investigate the transmission function model of the power system it is designed in MATLAB / SIMULINK environment. Frequency deviation, control area error, as well as tie-line power of the proposed duelist algorithm are analyzed and simulated. Here, the response is analyzed using two criteria

- Normal condition
- 1% step load perturbation

During these two conditions, the proposed method is analyzed, and then it is compared with the existing techniques such as PSO, BFO, ABC optimization algorithms. And it is seen that the proposed technique outperforms the existing ones.

A. Scenario 1: Normal Condition

At first, the area control error of the thermal, wind, hydro system is analyzed under normal conditions. Here the area error is less as compared to the existing techniques. Area control error of thermal, wind, and hydro areas, i.e., area 1, area 2, and area 3, are shown in Fig. 5, where the area control error is plotted against time. The area control error is varied with time from 0 to 30 sec .The error reaches the peak value of 0.23 in 0.1 sec. In area 2, area control error is varied from 0 to 30 sec. Error ranges from -0.05 to 0.18. In area 3, the error of the area is varied from -0.03 to 0.12 within a time of 0.1 sec. Figure 6 displays the comparison of area control error of DOA with the existing methods. Figure 6(a) displays the comparison of area control error of area 1with existing techniques. The area control error in the proposed technique is less as compared to other techniques, and also very little time is required. Fig.6 (b) displays the comparison of area control error of area 2 with existing techniques. Fig.6 (c) displays the comparison of area control error of area 3 with existing techniques. From these comparisons, it is observed that the performance of the proposed technique is very effective as compared to the existing ones. Fig.7 displays the frequency deviations in the proposed technique. Fig.7(a) shows the frequency deviation of the thermal system. The frequency deviation ranged from -0.08 to 0.298 HZ at a time interval of 0.5sec. The frequency deviation is varied from 0 to 30 sec, and after it is constant. The frequency deviation of the DOA technique in the wind system is displayed in Fig.7(b), and it ranged from -0.1 to 0.35 HZ at a time interval of 0.5sec. The frequency deviation of the hydro system is displayed in Fig.7(c), and it ranged from -0.05 to 0.28 HZ at a time interval of 0.5sec.

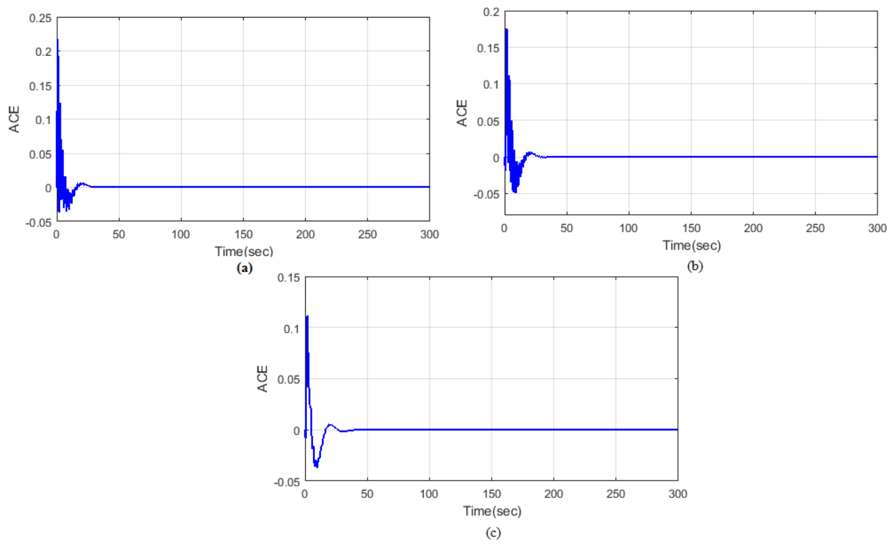


Fig.5. Area control error of thermal, wind, and hydro area

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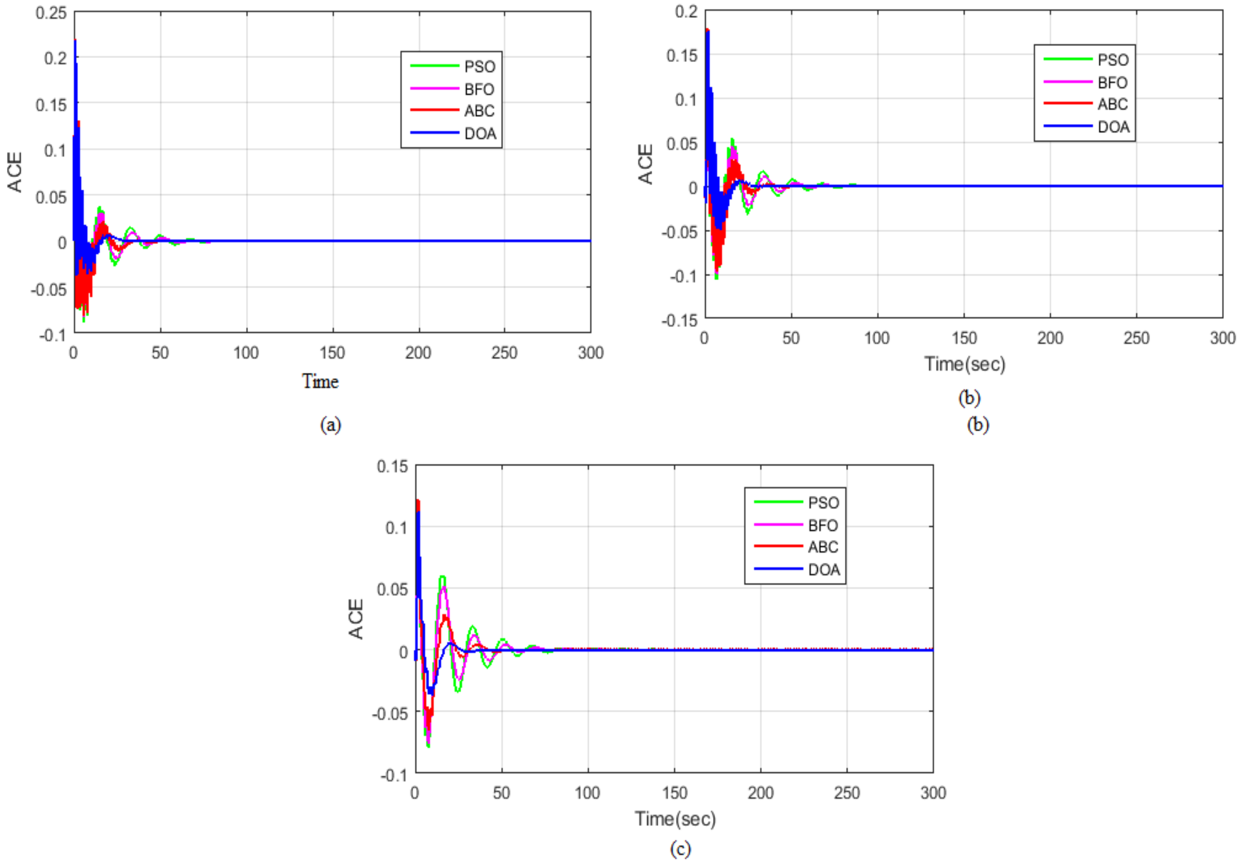

Fig.6. Comparison of area control error in the proposed DOA with existing techniques (a) thermal (b) wind (c) hydro

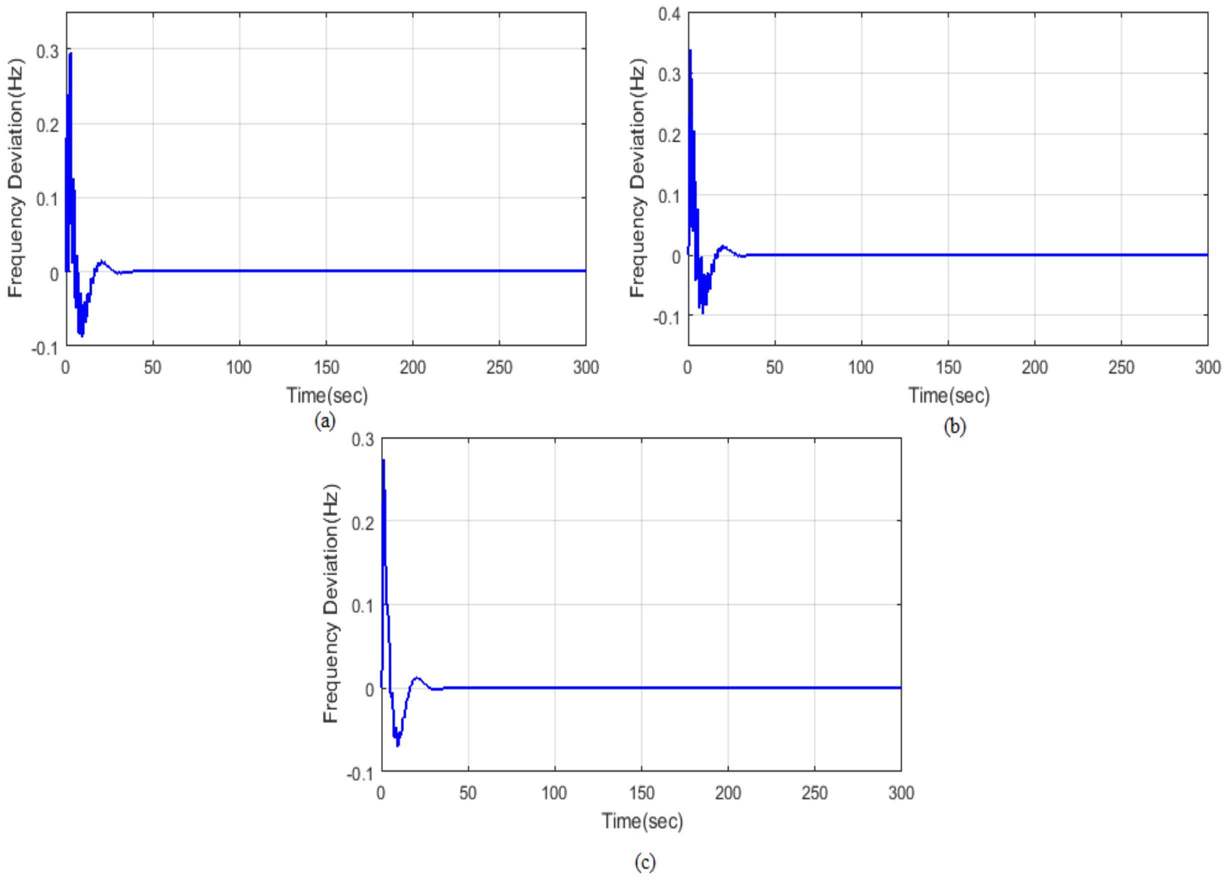

Fig.7. Frequency deviation of area 1, area 2, area 3

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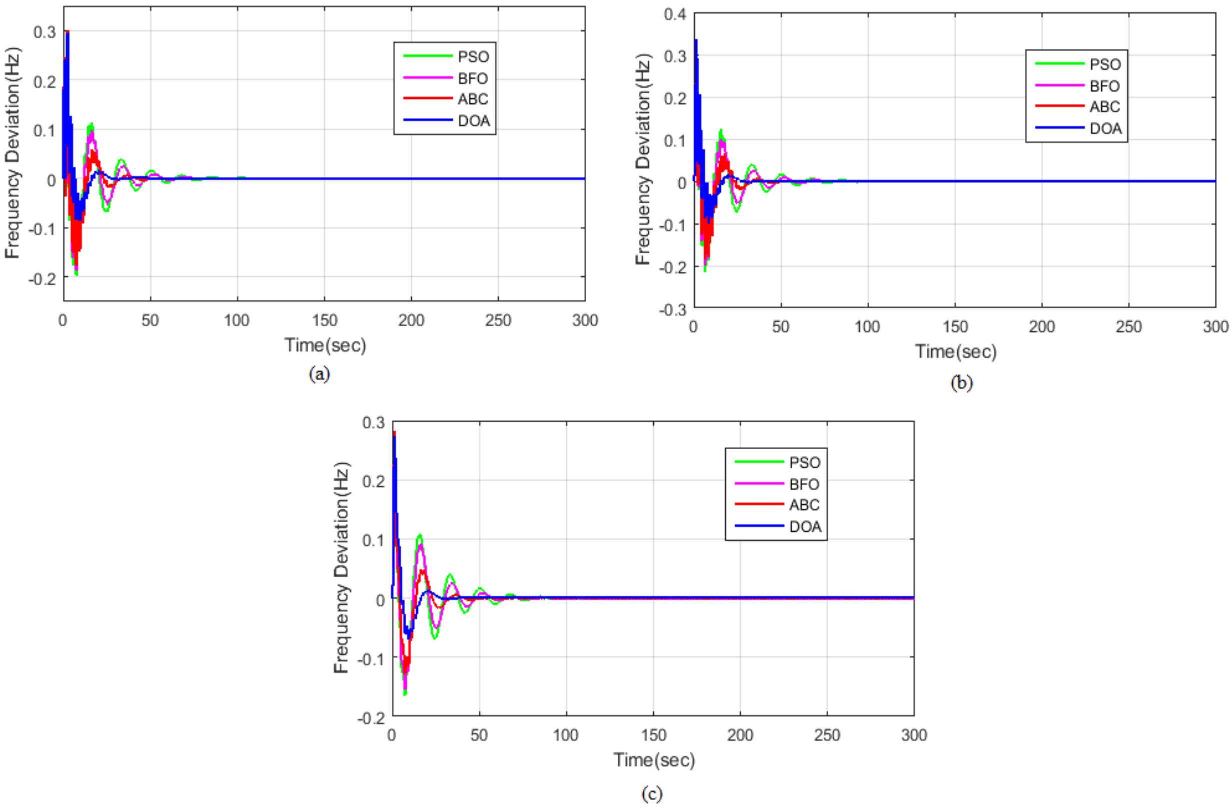

Fig.8. Comparison of Frequency deviation in the proposed DOA with existing techniques (a) thermal (b) wind (c) hydro systems

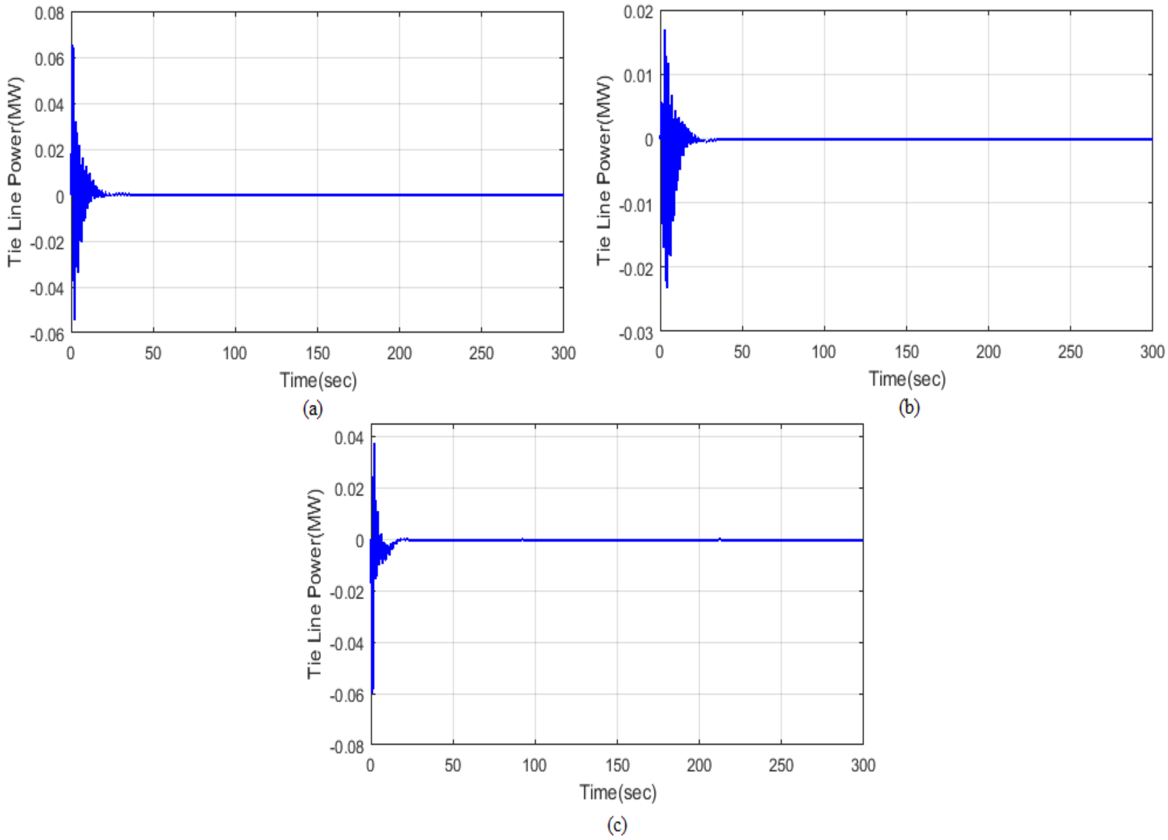

Fig.9. Tie line power of area 1, area 2, area 3

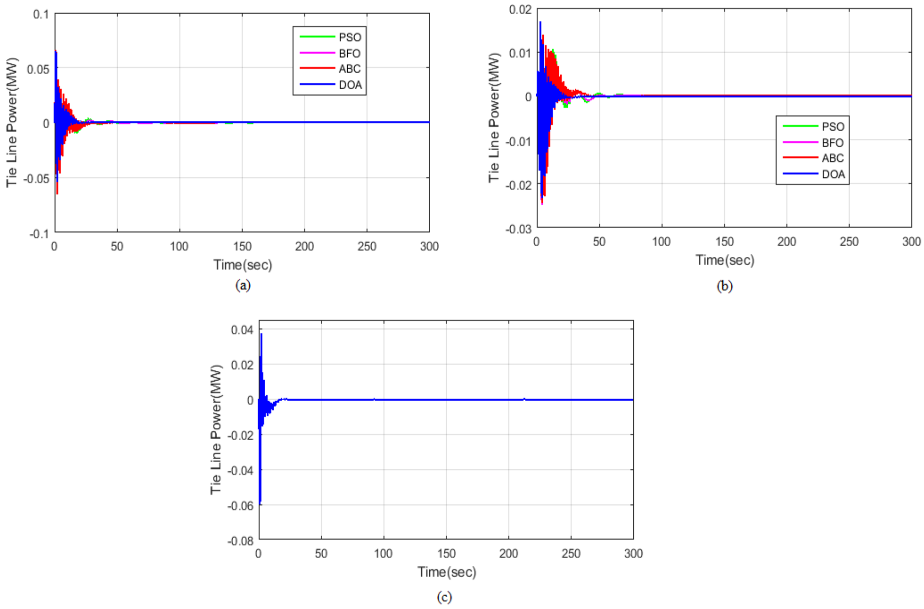

Fig.10. Comparison of tie-line power in DOA with existing techniques

Figure 8 displays the comparison of frequency deviation under DOA with existing methods. Area 1 frequency deviation is compared to existing methods shown in Figure 8 (a). A deviation is occurring at a time instant of 0 to 50 sec. Deviation of the proposed method is very low as compared to the existing methods. Area 2 frequency deviation is compared to the existing method and is displayed in Figure 8 (b). Area 3 frequency deviation is compared with the existing techniques, as shown in Figure 8(c). Figure 9 (a) shows the area 1 tie-line power. Tie line power also varied from -0.06 to 0.065 MW at a time interval of 0 to 0.5 sec. After that, it varied from 0 to 30 sec. Figure 9(b) displays area 2 tie line powers. Tie line power is also varied from -0.025 to 0.017 MW at a time interval of 0 to 0.5 sec. Figure 9 (c) shows the area 3 tie-line power which is varied from -0.06 to 0.037 MW. Fig 10 displays a comparison of tie-line power between the proposed technique with the existing techniques in the three areas interconnected power system.

B. Scenario 2: 1% load perturbation

The the system performance is again analysed using the proposed algorithm with 1% perturbation. At first area control error of thermal, wind, hydro system is analyzed. The error of the area is less with DOA as compared to the existing methods. Area control error of thermal area, i.e., area 1, is shown in fig. 11 (a), where it is plotted against time. The control area error is varied from 0 to 30 sec. At 0.1 sec, the error reaches the peak value of 0.18. Area control error of wind area, i.e., area 2, is shown in fig. 11 (b). The control area error is varied in time from 0 to 30 sec. At 0.1 sec, the error reaches the peak value of 0.16. Area control error of hydro area, i.e., area 3, is shown in fig 11 (c). The error is varied from -0.06 to 0.1.

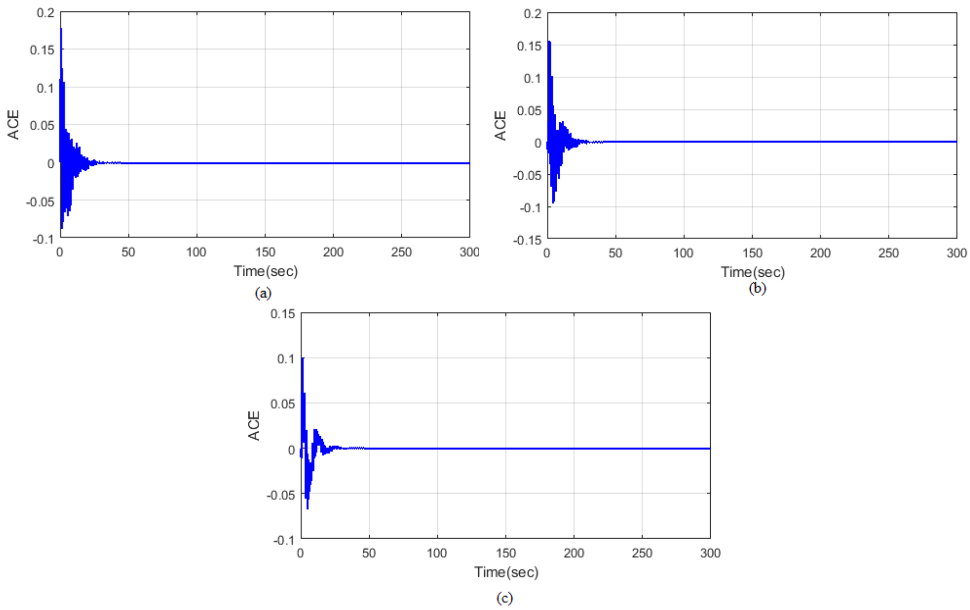

Fig.11. Area control error of (a) thermal (b) wind (c) hydro system

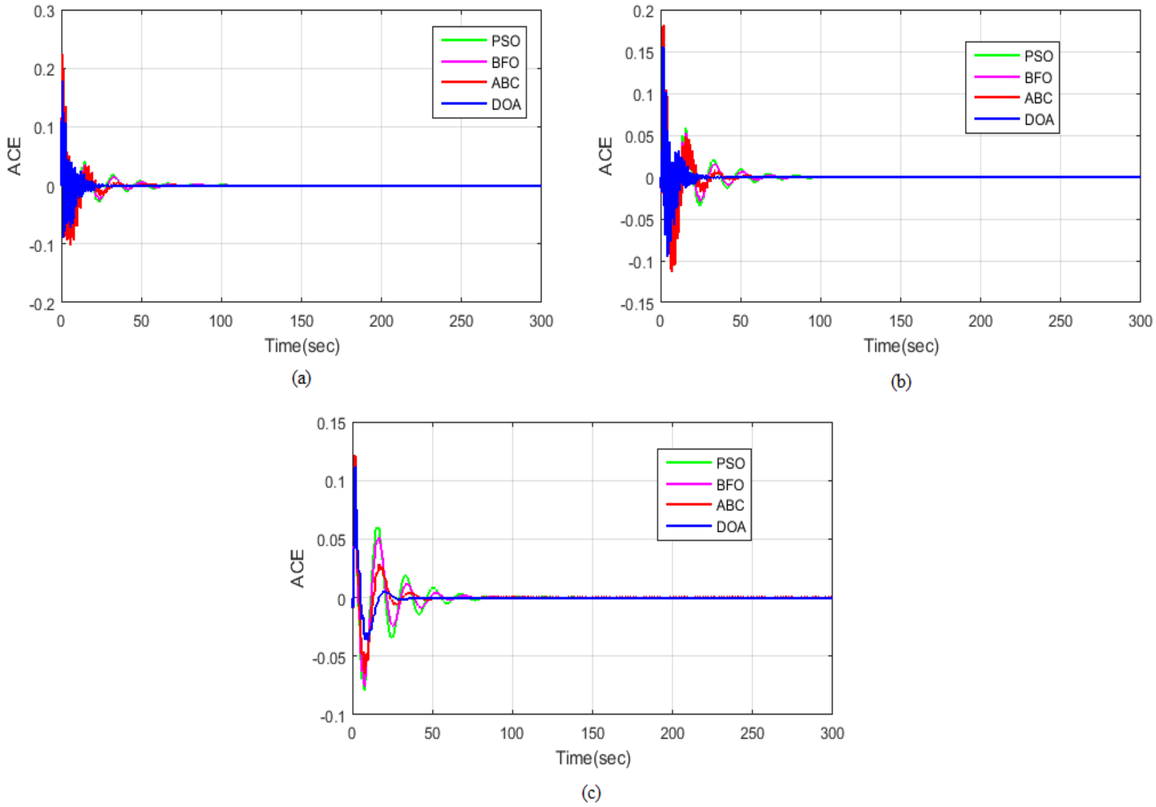

Fig.12. Area control error comparison of the proposed and existing techniques.

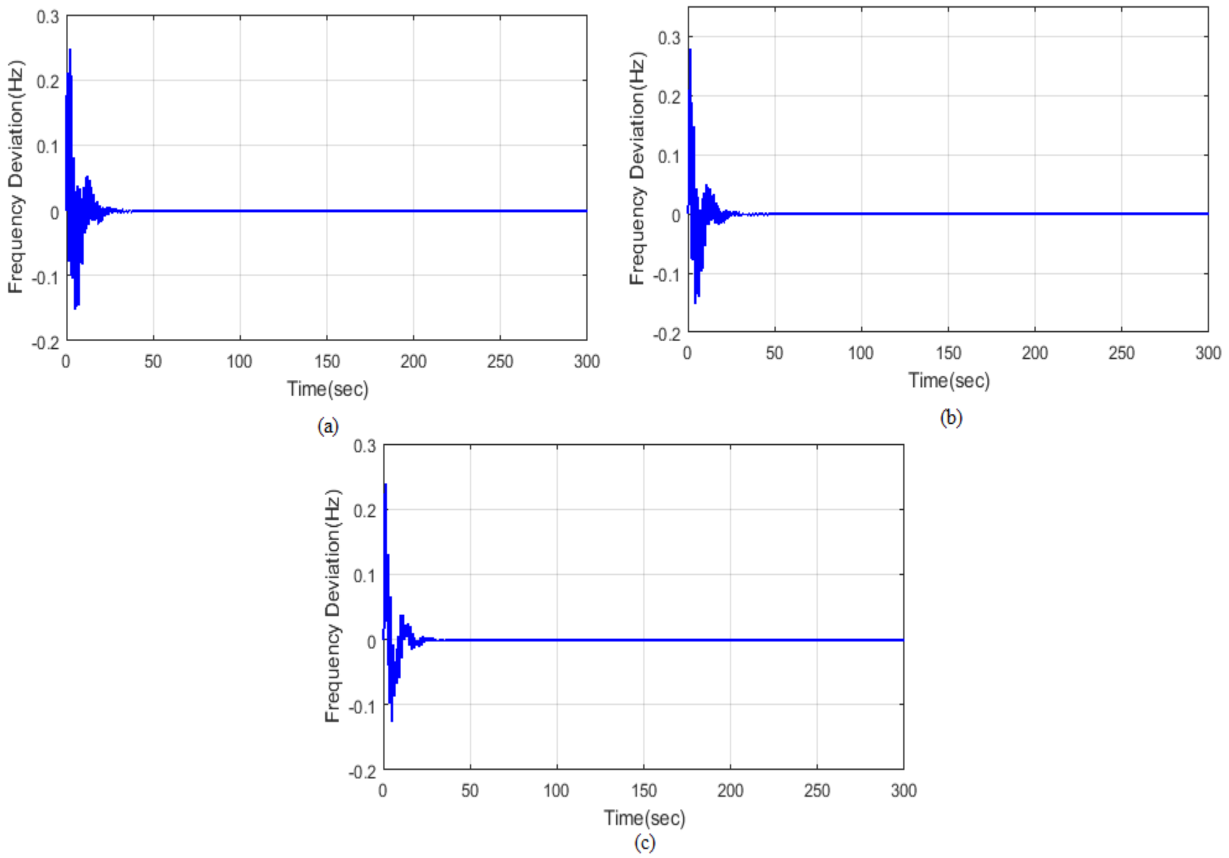

Fig.13. Frequency deviation of (a) thermal area, (b) wind area (c) hydro area

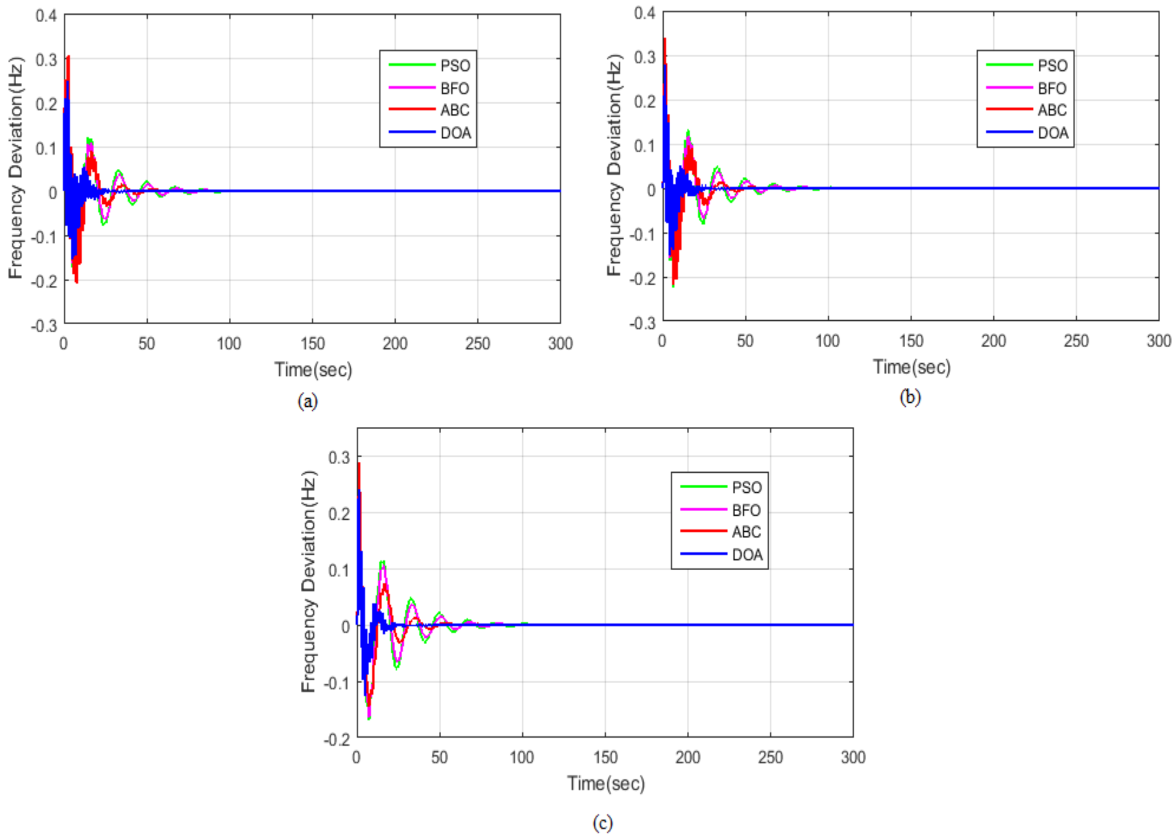

Fig.14. Comparison of frequency deviation in areas 1, 2, 3 of the proposed method with the existing methods

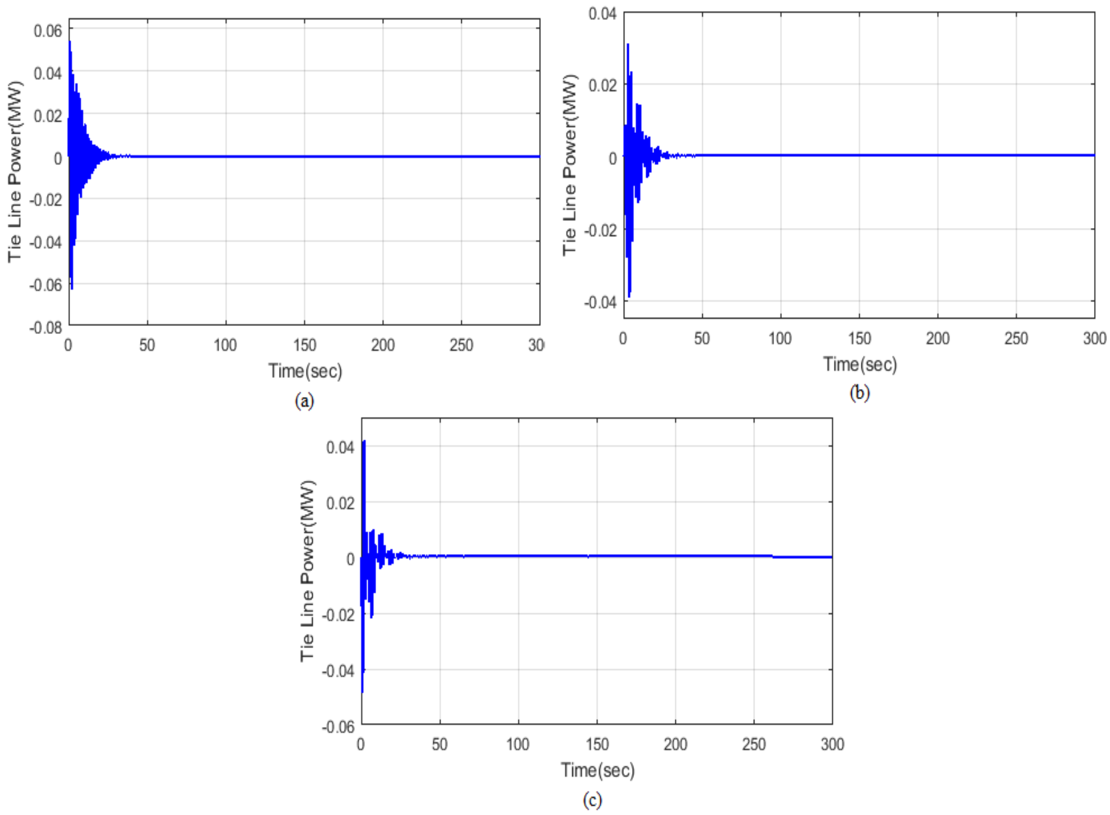

Fig.15. Tie-line power of (a) area 1, (b) area 2, (c) area 3

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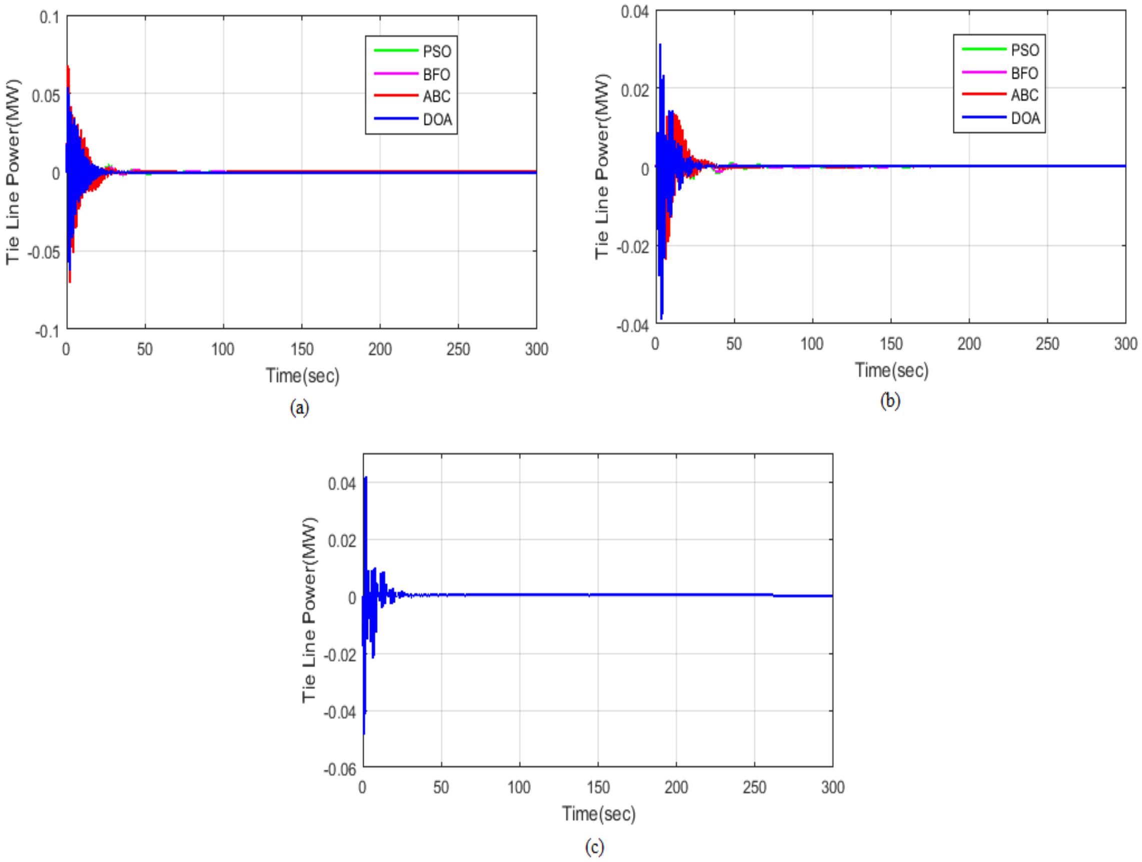

Fig.16. Tie Line Power Comparison Of The Proposed Method In Areas 1, 2, 3 With The Existing Methods

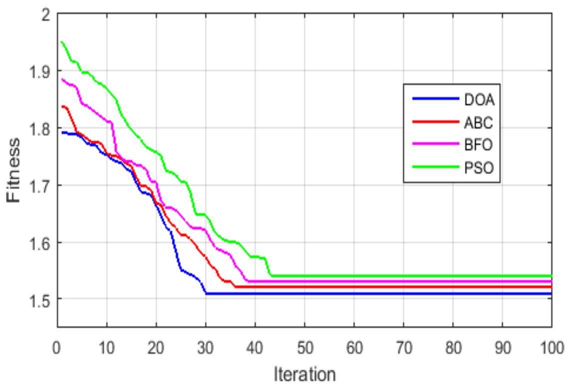

Fig.17. Fitness comparison of DOA and existing methods

Fig.12 displays the comparison of area control errors of DOA and the existing methods. Fig.13 (a) displays area 1 frequency deviation. Frequency deviation occurs at the starting stage. The value is varied from -0.15 to 0.25 Hz at a time interval of 0 to 5 sec. The deviation is varied from 0 to 30 sec. Fig.13 (b) displays the area 2 frequency deviation. The value is varied from -0.13 to 0.28 Hz at a time interval of 0 to 5 sec. Fig.13 (c) displays the area 3 frequency deviation. The value is varied from -0.12 to 0.25 Hz at a time interval of 0 to 5 sec. Fig.14 displays the comparison of the proposed method with the existing methods using frequency deviation. Fig.15 (a) displays the tie-line power of area 1. Tie line power is varying initially from -0.061 to 0.058 MW. It can vary up to 30 seconds, and after that, it provides constant power. Fig.15 (b) displays the tie-line power of area 2. Initially, it varied from -0.039 to 0.03 MW.

Fig.15 (c) shows the area 3 tie-line power and is varying at the range of -0.05 to 0.042 MW. Fig.16 displays the comparison of tie-line power based on DOA with the existing technique. Fig.17 displays DOA and existing technique fitness comparison. DOA technique fitness is 1.79, which is low as compared with existing techniques. From the fitness analysis, the proposed method gives better control than the existing techniques. The proposed and existing techniques are statistically analyzed in table 1. The mean of the proposed method is 1.5629 and median is 1.5107, and the standard deviation is 0.0946. This value is small as compared to the existing techniques. So it can be concluded that the proposed technique provides better results compared to the existing methods.

Table-1: Statistical Analysis of Proposed And Existing Methods

Method	Mean	Median	S.D
DOA	1.5629	1.5107	0.0946
ABC	1.5778	1.5205	0.0959
BFO	1.5974	1.5304	0.1076
PSO	1.6240	1.5401	0.1261

VII. CONCLUSION

In this manuscript, a DOA is proposed for adaptive controller parameter tuning and LFC tracking of the interconnected hybrid power system. The proposed method demonstrates the power system of three areas, e.g., thermal, wind, and hydro system.

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Zero steady-state error and reduction of unscheduled tie-line power flow under the control area is the objective of the proposed technique. In the proposed DOA technique, error and power flow are controlled. It is observed that the variation in the system frequency remains close to their nominal value; also the system output is controlled, and the power balance is preserved in load variations. Then, the DOA method is executed in MATLAB / Simulink platform, performance is analyzed, and then the results are compared with the existing methods like PSO, BFO, and ABC. The simulation results show that the DOA-based adaptive controller is robust in operation and provides excellent damping performance of frequency and tie-line power deviation compared to existing techniques.

REFERENCES

1. C. Pradhan and C. Bhende, "Online load frequency control in wind integrated power systems using modified Jaya optimization", *Engineering Applications of Artificial Intelligence*, vol. 77, pp. 212-228, 2019
2. K. Jagatheesan et al., "Application of flower pollination algorithm in load frequency control of multi-area interconnected power system with nonlinearity", *Neural Computing and Applications*, vol. 28, no. 1, pp. 475-488, 2016.
3. G. Shankar and V. Mukherjee, "Quasi oppositional harmony search algorithm-based controller tuning for load frequency control of multi-source multi-area power system", *International Journal of Electrical Power & Energy Systems*, vol. 75, pp. 289-302, 2016
4. M. Qais, H. Hasanien and S. Alghuwainem, "Whale optimization algorithm-based Sugeno fuzzy logic controller for fault ride-through improvement of grid-connected variable speed wind generators", *Engineering Applications of Artificial Intelligence*, vol. 87, p. 103328, 2020.
5. M. Khosraviani, M. Jahanshahi, M. Farahani, and A. Bidaki, "Load–Frequency Control Using Multi-objective Genetic Algorithm and Hybrid Sliding Mode Control-Based SMES", *International Journal of Fuzzy Systems*, vol. 20, no. 1, pp. 280-294, 2017.
6. M. Khooban, T. Niknam, F. Blaabjerg, and T. Dragičević, "A new load frequency control strategy for micro-grids with considering electrical vehicles", *Electric Power Systems Research*, vol. 143, pp. 585-598, 2017
7. G. Nguyen, K. Jagatheesan, A. Ashour, B. Anand and N. Dey, "Ant Colony Optimization Based Load Frequency Control of Multi-area Interconnected Thermal Power System with Governor Dead-Band Nonlinearity", *Lecture Notes in Networks and Systems*, pp. 157-167, 2017.
8. M. Chen, G. Zeng and X. Xie, "Population extremal optimization-based extended distributed model predictive load frequency control of multi-area interconnected power systems", *Journal of the Franklin Institute*, vol. 355, no. 17, pp. 8266-8295, 2018.
9. C. Peng, J. Zhang and H. Yan, "Adaptive Event-Triggering ${H}_{\infty }$ Load Frequency Control for Network-Based Power Systems", *IEEE Transactions on Industrial Electronics*, vol. 65, no. 2, pp. 1685-1694, 2018
10. K. Rajesh and S. Dash, "Load frequency control of autonomous power system using adaptive fuzzy based PID controller optimized on improved sine cosine algorithm", *Journal of Ambient Intelligence and Humanized Computing*, vol. 10, no. 6, pp. 2361-2373, 2018.
11. J. Mudi, C. Shiva and V. Mukherjee, "Multi-verse Optimization Algorithm for LFC of Power System with Imposed Nonlinearities Using Three-Degree-of-Freedom PID Controller", *Iranian Journal of Science and Technology, Transactions of Electrical Engineering*, vol. 43, no. 4, pp. 837-856, 2019.
12. [12] C. Mu, Y. Tang and H He, "Improved Sliding Mode Design for Load Frequency Control of Power System Integrated an Adaptive Learning Strategy", *IEEE Transactions on Industrial Electronics*, vol. 64, no. 8, pp. 6742-6751, 2017.
13. P. Ojaghi and M. Rahmani, "LMI-Based Robust Predictive Load Frequency Control for Power Systems With Communication Delays", *IEEE Transactions on Power Systems*, vol. 32, no. 5, pp. 4091-4100, 2017.
14. M. Mohamed, A. Diab, H. Rezk and T. Jin, "A novel adaptive model predictive controller for load frequency control of power systems integrated with DFIG wind turbines", *Neural Computing and Applications*, vol. 32, no. 11, pp. 7171-7181, 2019.
15. Z. Yan and Y. Xu, "Data-Driven Load Frequency Control for Stochastic Power Systems: A Deep Reinforcement Learning Method with Continuous Action Search", *IEEE Transactions on Power Systems*, vol. 34, no. 2, pp. 1653-1656, 2019.
16. R. Khadanga, S. Padhy, S. Panda, and A. Kumar, "Design and Analysis of Tilt Integral Derivative Controller for Frequency Control in an Islanded Microgrid: A Novel Hybrid Dragonfly and Pattern Search Algorithm Approach", *Arabian Journal for Science and Engineering*, vol. 43, no. 6, pp. 3103-3114, 2018.
17. K. Liao and Y. Xu, "A Robust Load Frequency Control Scheme for Power Systems Based on Second-Order Sliding Mode and Extended Disturbance Observer", *IEEE Transactions on Industrial Informatics*, vol. 14, no. 7, pp. 3076-3086, 2018.
18. H. Yousef, "Adaptive fuzzy logic load frequency control of multi-area power system", 2020.
19. P. Venkaiah and B. Sarkar, "Hydraulically actuated horizontal axis wind turbine pitch control by model-free adaptive controller", *Renewable Energy*, vol. 147, pp. 55-68, 2020
20. D. Guha, P. Roy and S. Banerjee, "Load frequency control of large scale power system using quasi-oppositional grey wolf optimization algorithm", *Engineering Science and Technology, an International Journal*, vol. 19, no. 4, pp. 1693-1713, 2016.
21. H. Hasanien and A. El-Fergany, "Salp swarm algorithm-based optimal load frequency control of hybrid renewable power systems with communication delay and excitation cross-coupling effect", *Electric Power Systems Research*, vol. 176, p. 105938, 2019
22. S. Abd-Elazim and E. Ali, "Load frequency controller design of a two-area system composing of PV grid and thermal generator via firefly algorithm", *Neural Computing and Applications*, vol. 30, no. 2, pp. 607-616, 2016.
23. D. Guha, P. Roy and S. Banerjee, "Whale optimization algorithm applied to load frequency control of a mixed power system considering nonlinearities and PLL dynamics", *Energy Systems*, vol. 11, no. 3, pp. 699-728, 2019. Available: 10.1007/s12667-019-00326-2 [Accessed 8 August 2020].
24. S. Nosratabadi, M. Bornapour and M. Gharaei, "Grasshopper optimization algorithm for optimal load frequency control considering Predictive Functional Modified PID controller in restructured multi-resource multi-area power system with Redox Flow Battery units", *Control Engineering Practice*, vol. 89, pp. 204-227, 2019.
25. M. Gheisarnejad, "An effective hybrid harmony search and cuckoo optimization algorithm based fuzzy PID controller for load frequency control", *Applied Soft Computing*, vol. 65, pp. 121-138, 2018.
26. K. Lu, W. Zhou, G. Zeng and Y. Zheng, "Constrained population extremal optimization-based robust load frequency control of multi-area interconnected power system", *International Journal of Electrical Power & Energy Systems*, vol. 105, pp. 249-271, 2019.
27. A Latif, D. Das, A. Barik and S. Ranjan, "Maiden coordinated load frequency control strategy for ST-AWEC-GEC-BDDG-based independent three-area interconnected microgrid system with the combined effect of diverse energy storage and DC link using BOA-optimised PFOID controller", *IET Renewable Power Generation*, vol. 13, no. 14, pp. 2634-2646, 2019.
28. R. Ramachandran, B. Madasamy, V. Veerasamy and L. Saravanan, "Load frequency control of a dynamic interconnected power system using generalized Hopfield neural network based self-adaptive PID controller", *IET Generation, Transmission & Distribution*, vol. 12, no. 21, pp. 5713-5722, 2018.
29. C. Pezzato, R. Ferrari and C. Corbato, "A Novel Adaptive Controller for Robot Manipulators Based on Active Inference", *IEEE Robotics and Automation Letters*, vol. 5, no. 2, pp. 2973-2980, 2020.
30. H. Li, X. Wang and J. Xiao, "Adaptive Event-Triggered Load Frequency Control for Interconnected Microgrids by Observer-Based Sliding Mode Control", *IEEE Access*, vol. 7, pp. 68271-68280, 2019.
31. J. Guo, "Application of full order sliding mode control based on different areas power system with load frequency control", *ISA Transactions*, vol. 92, pp. 23-34, 2019.
32. D. Guha, P. Roy and S. Banerjee, "Load frequency control of interconnected power system using grey wolf optimization", 2020. .
33. L. Dong, Y. Tang, H. He and C. Sun, "An Event-Triggered Approach for Load Frequency Control with Supplementary ADP", *IEEE Transactions on Power Systems*, vol. 32, no. 1, pp. 581-589, 2017
34. D. Guha, P. Roy and S. Banerjee, "Grasshopper optimization algorithm scaled fractional order PI-D controller applied to reduced order model of load frequency control system", *International Journal of Modelling and Simulation*, vol. 40, no. 3, pp. 217-242, 2019.

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35. T. Biyanto et al., "Techno Economic Optimization of Petlyuk Distillation Column Design Using Duelist Algorithm", *Procedia Engineering*, vol. 170, pp. 520-527, 2017

AUTHORS PROFILE

Nipan Kumar Das, currently working as an Assistant Professor in Department of Electrical Engineering at Jorhat Engineering College, Assam received Bachelor of Engineering in Electrical Engineering from Assam Engineering College affiliated to Gauhati University. He pursued his Master of Engineering in Electrical Engineering with specialization in Instrumentation and Control Engineering from Jorhat Engineering College. He is currently working toward the Ph.D. degree in the Department of Electrical Engineering at Jorhat Engineering College. His research interests include soft computing applications in power system Engineering. Some of his Research Publications are, "A Neoteric Closed Loop Feedback Controller based on correlative-elemental curvature algorithm" in Circuit World, ISSN: 0305-6120 Emerald publishing, June 2021, "Design of a Robust Nonlinear Controller for a Synchronous Generator to Enhance Transient Stability" published at the IEEE conference-2018, ID: 978-1-5386-4769-1/18/$31.00 ©2018 IEEE, "Fuzzy Logic Control based Internal Model Control scheme and Model Order Reduction for load frequency control in power system" published at the International Journal of Industrial Electronics and Electrical Engineering, ISSN: 2347-6982, Volume-7, Issue-9, Sep.-2019.

Papu Moni Saikia, currently working as Assistant Professor in the Department of Electrical Engineering atJorhat Engineering College, Assam received Bachelor of Engineering in Electrical Engineering from Assam Engineering College affiliated to Gauhati University. He pursued his Master of Engineering in Electrical Engineering with specialization in Instrumentation and Control Engineering from Jorhat Engineering College. He is currently working toward the Ph.D. degree in the Department of Electrical Engineering at Jorhat Engineering College. His research interests include soft computing applications in power system Engineering. His Research paper titled "Design of a Wireless Sensor Network in Early Landslide Detection" got published in the International Journal of New Technologies in Science and Engineering, ISSN: 2349-0780, Vol.5, Issue-3.

Dr. Mrinal Buragohain, currently working as a Professor in the Department of Electrical Engineering at Jorhat Engineering College, Jorhat received his Bachelor of Engineering in Electrical Engineering from Assam Engineering College affiliated to Gauhati University, Assam. He pursued his Master of Engineering in High Voltage Engineering from Jadavpur University, Kolkata. After this, he completed his Ph.D. with specialization in Control System in the department of Electronics and Communication Engineering at the Indian Institute of Technology, Guwahati. His research interests include soft computing application in non-linear systems and Optimal and adaptive control. Some of his Research publications are "Tracking and Synchronization of A Hyperchaotic Hyperjerk system with No Equilibria Using Back stepping Control" at International journal for Research in Engineering Application & Management, ISSN: 2454-9150, Vol-05, Issue-02, May 2019, " A PID Adaptive Sliding Mode Control for an Inverted Pendulam System for an External Disturbance using Grey Wolf Optimization Technique" at International Journal of New Technologies in Science and Engineering, ISSN: 2349-0780, Vol. 5, Issue.3, 2018.

Nikhil Saikia, pursued his Bachelor of Engineering in Electrical Engineering from Girijananda Chowdhury Institute of Management and Technology (GIMT), affiliated to Gauhati University, Assam. He is currently working towards the Master in Technology with specialization in Instrumentation and Control Engineering in the department of Electrical Engineering at Jorhat Engineering College, affiliated to Dibrugarh University, Assam. His research interest includes soft computing applications in power system engineering,. He has a experience of working as a Project Engineer in REC Power Development and Consultancy Limited (RECPDCL) (formerly REC Power Distribution Company Limited) for a period of about 30 months.

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