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A Neural Network-Bacterial Foraging Algorithm to Control the Load Frequency of Power System

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Abstract: In this paper, a neural network (NN)-bacterial foraging algorithm (BFA) is proposed to control the load frequency of the power system. Traditionally, the tumbling decision element of BFA is defined by the stochastic values. But, these values are changed as per the variations of chemotactic step size so that the convergence time is increased. Here, NN is used to ensure the distribution of stochastic value with respect to the chemotactic step size and thus the performance of BFA is enhanced. The feed forward NN is used here with back propagation training algorithm. Using the proposed controller, the controller error, load changes, and speed changer position are tuned and the stability of the interconnected power system is improved. The proposed tuning controller is implemented in MATLAB/Simulink platform and the load frequency control responses are evaluated. The performances of proposed controller are compared with those of the PID controller and the BFA-PID controller.

Keywords: Load frequency control, power system, tuning algorithm, BFA, adaptive BFA.

1. Introduction

The persistent rise of power demand in the electric power market invariably raises the size and difficulty of the power system [1]. Large scale power systems are generally compiled of inter-related subsystems or multi-control areas [2]. Renewable energy sources are launched for installation in the modern power system as distributed generators (DGs) due to the reasons of pollution and degradation of fossil fuels, which raises further difficulty. In the operation and plan of the power system, these kinds of interconnected subsystems are posing a great challenge [3]. In multi-area based power systems, the generation inside every area has to be so managed as to uphold the programmed power interchange which is executed by either tie-lines or HVDC links [4]. A well planned and operated power system must deal with changes in the load and with system disturbances, and it should offer good enough high level of power quality while sustaining both voltage and frequency within tolerance limits [5][6].

The power quality of the power systems is thought to be having steady frequency and must uphold the programmed power and voltage [7]. If the power system is subjected to any disturbances, the nominal operating point of a power system alters from its pre-specified value which causes the variation in nominal system frequency and the programmed power exchange to the other regions [8]. Since frequency is a general factor all over the systems, any transform in active power demand/generation is replicated throughout the system by a variance in frequency [9] [10] [11]. Commotions like load variations cause wear and tear on governor tools and shorten their lifetime which paves the way for further equipment cost for a year. It is essential to plan the controllers as the loading in a power system is not at all steady, so as to keep the system frequency and the inter-area tie-line power as near the programmed values as feasible [12].

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Within the particular limits, the control of real power output of generating units, in retort to changes in system frequency and tie-line power interchange is known as load frequency control (LFC) [13][14][15]. LFC is as well known as Automatic Generation Control (AGC) [16] which turns more important today with the increasing size and difficulty of inter-connected power systems. In multi-faceted multi-area power system networks, it is one of most important constraints offering dependable and quality operation [17]. The objectives of the LFC are to preserve zero steady state faults in a multi-area inter-connected power system and to complete the demanded dispatch conditions [18] [19] plus it has to be vigorous against unidentified external disturbances along with system model and parameter uncertainties [20]. Several researches are in the stage of development to work out the LFC problem in modern power system networks. A few of the strategies for working out the LFC are such as Dynamical Fuzzy Network (DFN), dynamic wavelet network (DWN), two-level structure, decentralized adaptive control scheme, Robust analysis, fuzzy logic controller (FLC), particle swarm optimization (PSO) algorithm, DE optimized parallel 2-DOF PID controller, dual mode controllers, output feedback controller, Fuzzy C-Means clustering technique, FACTS-IPFC, Neural network model predictive control (NN-MPC), Genetic Algorithm (GA), Bacteria Foraging Optimization Algorithm (BFOA), PID controller etc [20].

Naturally, the PID type controllers are applied, but the control action of this type of controllers is dependent on the turning gains. Recently, the global optimization method like GA has distressed the deliberation in the field of controller parameter optimization. The computational difficulty of this population based algorithm is raised owing to the consideration of genetic operators. For modeling and perception of evolutionary species, the foraging behavior is appropriate, thus it is applied as an optimization algorithm in the frequency control of the power system. The unit length of direction and the step length of the related bacterium are identified arbitrarily in the bacterial foraging algorithm. Hence, the optimal solution convergence time is raised for making sure the specified problem. In the paper, NN-BFA based PID controller tuning algorithm is proposed to control the load frequency changes of power system. The detailed description of proposed control model is discussed in Section 3. Before that, the recent research works are presented in Section 2, the results and analysis is presented in Section 4 and Section 5 concludes the paper.

2. Literature Review

Handful research works existed in literatures which are based on load frequency control of power system. Some of them are reviewed here. An approach for working out this problem, F. Daneshfar *et al*. [21] have offered because of the allocated nature of a multi-area power system by means of a multi-agent reinforcement learning (MARL) strategy. In each power area, it was comprised of two agents; the estimator agent offers the area control error (ACE) signal based on the frequency bias estimation and the controller agent employs reinforcement learning to manage the power system in which genetic algorithm optimization was applied to adjust its parameters. This technique does not depend on any knowledge of the system and it declares significant litheness in defining the control objective. Moreover, by finding the ACE signal based on frequency bias estimation the LFC presentation was enhanced and by applying the MARL parallel, computation was understood, leading to a high degree of scalability.

Wen Tan [22] has conversed a combined PID tuning technique for load frequency control (LFC) of power systems. The tuning technique was based on the two-degree-of-freedom (TDF) internal model control (IMC) design technique and a PID approximation process. The time-domain presentation and toughness of the resulting PID controller was associated to two tuning parameters, and robust tuning of the two parameters was conversed. The technique was appropriate to power systems with non-reheated, reheated, and hydro turbines. Simulation results explain that it can be certainly develop the damping of the power systems. It was demonstrated that the technique can furthermore be applied in decentralized PID tuning for multi-area power systems.

A hierarchical optimal robust controller for the power system load-frequency control problem has been offered by M. Rahmani *et al.* [23]. The multi-area power system was crumbled into numerous sub-systems. After that, by applying a two level control approach the overall optimal solution was attained. At the initial level, the optimal control of every area was attained with respect to local data and furthermore regarding interactions coming from other regions. At the second level, by applying a coordination approach, the local controllers would be congregated to global solution and optimal robust controller was attained. Simulation results demonstrate the efficiency and optimality of the vigorous controller in power systems.

To work out the load-frequency control (LFC) problem, M. Farahani *et al*. [24] have suggested a PID optimized by the lozi map based chaotic algorithm (LCOA). The PIDs tuned by the LCOA are employed in each area for a two-area power system. The simulation effects were applied to show the efficiency and presentation of the suggested controller. It was explained that optimized PID was proficient to work out the LFC problem and furthermore the presentation of the system in every area was adequate. Besides, a relative study was executed between the results attained from PID tuned by the LCOA and the other optimization algorithms.

Reza Farhangi *et al.* [25] have suggested a strategy based on the emotional learning is proposed for enhancing the load–frequency control (LFC) system of a two-area interrelated power system with the deliberation of generation rate constraint (GRC). The controller comprises a neuro-fuzzy system with power fault and it's imitative as inputs. A fuzzy critic assesses the current situation, and offers the emotional signal. The controller adapts its features so that the critic's stress was diminished.

E.S. Ali *et al*. [26] have suggested BFOA to adjust the parameters of PID controller for nonlinear LFC problem. To express the suggested method, a two area power system was regarded. An integral time absolute fault of the frequency variation of both areas and tie line power was taken as the objective function to develop the system response in terms of the settling time and overshoots. Simulation effects stress that the planned BFOA tuning PID controller was vigorous in its operation and offers a superb damping performance for frequency and tie line power variation was compared to conventional PID controller and GA tuning PID controller.

For working out the load frequency control problem of multi source multi area hydro thermal power system, variable structure fuzzy gain scheduling has been suggested by K.R.M. Vijaya Chandrakalam *et al.* [27]. The area frequency and tie line power fluctuates during load deviations were managed by primary governor controller and secondary Proportional Integral controller. By means of Ziegler Nichols' technique, the PI controller gains were adjusted and Genetic Algorithm. In both the techniques, the gain values of PI controllers were fixed for any system changes. This problem was prevailed over by scheduling the gain based on system changes by means of Fuzzy Logic. Lastly, Variable Structure System of switching P to PI controller during transient to solid state was incorporated with fuzzy gain scheduling.

Mehdi Rahmani *et al.* [28] have offered a two-level structure to attain optimal solution for LFC problems and furthermore decrease the computational complexity of centralized controllers. In this strategy, an interrelated multi-area power system was crumbled into numerous sub-systems at the primary level. After that an optimization problem in every area was worked out independently, regarding its local data and interaction signals coming from other regions. At the second-level, by revising the interaction signals and by means of an iterative procedure, the local controllers will congregate to the overall optimal solution. By parallel working out of areas, the computational time of the algorithm was diminished in contrast to centralized controllers.

Chuan-Ke Zhang *et al*. [29] have suggested a delay-dependent robust technique for analysis/synthesis of a PID-type LFC scheme regarding time delays. The outcome of the disturbance on the controlled output was described as a robust performance index (RPI) of the closed-loop system. At first, for a fixed delay upper bound, controller gains were found out by minimizing the RPI. Secondly, calculation of the RPIs of the closed-loop system under dissimilar delays offers a way to evaluate robustness against delays and calculate approximately delay margins. Correspondingly, case studies were based on three area LFC plans under traditional and deregulated atmospheres. The effects demonstrate that the PID-type controller attained could be guarantee the patience for delays less than the preset upper bound and offer a bigger delay margin than the presented controllers.

Sahaj Saxena *et al*. [30] have demonstrated the LFC problem as a distinctive disturbance rejection with large-scale system control problem. For this reason, easy strategy to LFC plan for the power systems containing parameter uncertainty and load disturbance was suggested. The strategy was based on two-degree-of-freedom, internal model control (IMC) plan, which combines the idea of model order reduction like Routh and Pade approximations, and adopted IMC filter plan. They has been regarded that in place of taking the full-order system for internal-model of IMC, a lower-order, i.e., second order reduced system copy. This plan accomplishes enhanced closed-loop system performance to work against load disturbances. The suggested strategy was replicated in MATLAB environment for a single-area power system comprising of single generating unit with a non-reheated turbine to emphasize the competence and effectiveness in terms of toughness and optimality.

3. Linear system model of interconnected two area power system

An accurate forecast of active power demand can be established by maintaining the frequency and reduce the uncertain load variation of the system throughout the day. The unbalance of active generation power, load demand and power losses affected the daily load cycle. It also, causes kinetic energy of alternation to additional or in use since the on line generating units and frequency all over the unified system diverges as a result. The definite power flows and the system frequency of neighbouring areas are observed by control area element which is the energy control centre. The linear structure of two area system is illustrated in Figure 1.

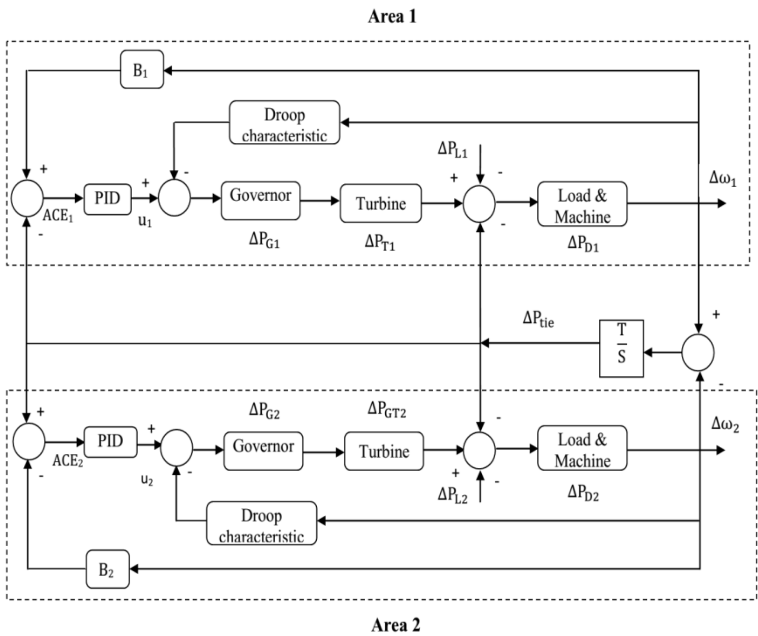

Figure 1. Linear structure model of two area system.

In the above diagram, ACE_1 and ACE_2 are the area control errors of the two area systems which are the difference between the preferred and real system frequencies. Subsequently, it is shared with the variation of the planned remaining exchange to form a complex calculation. For suitable operation of the power units, the frequency and the tie line power are predetermined as per the supposed and scheduled values even while the load changes and consequently eliminates the area control error (ACE_1=ACE_2=0). To reduce the control action of power plant of load frequency controller, the consideration of boiler turbine generator arrangement of thermal generation unit is needed. The purpose of the speed governor is to monitor the turbine generator speed and the frequency response is adjusted by controlling the valves. Since all the movements are marginal, the frequency power relation for turbine governor control can be studied by a linearised block diagram. However, the computer simulation will be carried out using the actual non-linear system.

In the given model, the generation source of mechanical power which is recognized as the most important exciter may possibly be either hydraulic, gas or thermal turbines. To vary the mechanical power of the turbine, the input valve of the turbine is adjusted by sensing the output changes of turbine [31]. Electrical loads are devices which consume the electrical power generated by the generator. For the purpose of stable performance with increasing load, the speed of the governor should be decreased. The model contains the consequence of generation rate limitation on the generator and the restrictions on the setting of the governor valve [35]. ΔP_G and ΔP_T are the incremental variations in the governor valve position and output mechanical power of turbine correspondingly. The control objective in the LFC problem is to keep the change in frequencies in addition to the change in tie-line power P_{tie} as secured to zero as attainable while the system is focused to load disturbance ΔP_D by influencing the inputs u_1 and u_2.

In figure 1, the control model of the system is presented with the Laplace domain models of the drop characteristics, the governor, the turbine, and the load in figure 2. The equations as well as the control model are illustrated as follows:

$$\textbf{\textit{Drop Characteristics}} = \frac{1}{\boldsymbol{R}}$$

$$\textbf{\textit{Governor}} = \frac{1}{1+\boldsymbol{sT_G}}$$

$$\textbf{\textit{Turbine}} = \frac{1}{1+\boldsymbol{sT_T}}$$

$$\textbf{\textit{Load \& Machine}} = \frac{1}{1+\boldsymbol{sT_P}}$$

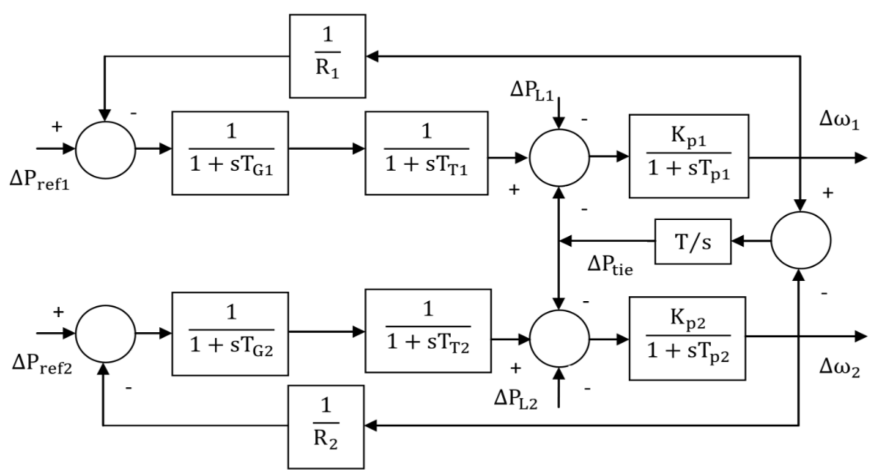

Figure 2. Two area system along with control model.

PID controller

The PID controllers are one of the most successful and influential control instruments in industry because of uncomplicated and simple implementation [32] [33]. The transfer function model of the PID controller in terms of the Laplace domain is described as follows:

$$G_{PID}(s) = \frac{U(s)}{E(s)} = K_P + K_I s + \frac{K_D}{s} \tag{1}$$

Where, U(s) and E(s) are the control signal and the error signal which is the difference between input and feedback in terms of Laplace domain correspondingly; K_P is the proportional gain, K_I , the integration gain, and K_D , the derivative gain. The output of PID controller in terms of time domain is represented as follows:

$$u(t) = K_P e(t) + K_I \int_0^t e(t)dt + K_D \frac{de(t)}{dt} \tag{2}$$

Where, u(t) and e(t) are the control and tracking error signals which are in the form of time domain. Here, u (t) and e(t) are varied depending on area 1 and area 2 and so, the control and error signal of area 1 are represented as $u_1(t)$ and $e_1(t)$; the control and error signals of area 2 are represented as $u_2(t)$ and $e_2(t)$ respectively. The error tracking signals $e_1(t)$ and $e_2(t)$ are the areas of control ACE_1 and ACE_2. Hence, the equation (2) is modified and rewritten as follows:
For area1:

$$u_1(t) = K_P ACE_1(t) + K_I \int_0^t ACE_1(t)dt + K_D \frac{dACE_1(t)}{dt} \tag{3}$$

For area2:

$$u_2(t) = K_P ACE_2(t) + K_I \int_0^t ACE_2(t)dt + K_D \frac{dACE_2(t)}{dt} \tag{4}$$

In equation (3) and (4), areas of control ACE_1 and ACE_2 are described in time domain as follows:

$$ACE(t) = \begin{cases} \Delta P_{tie}(t) + B_1 \Delta\omega_1(t) & \text{for Area } 1 \\ \Delta P_{tie}(t) + B_2 \Delta\omega_2(t) & \text{for Area } 2 \end{cases} \tag{5}$$

The output of the controller depends on the values of the PID controller gain such as K_P, K_I, and K_D respectively. Various PID controller parameter tuning methods are used for the decentralized power system load frequency controller [36]. The global optimization techniques like GA have concerned themselves with the consideration in the field of the controller parameter optimization. Due to consideration of the genetic operators, the computational complexity of the population based algorithm is increased [34]. The foraging behavior is suitable for the modeling and understanding of evolutionary species, hence it is used as an optimization algorithm for the frequency control of power system. In the bacterial foraging algorithm, the unit length of direction and the step length of that bacterium are defined randomly. So, the optimal solution convergence time is increased for addressing the given problem [37].

In this paper, the NN-BFA is proposed to control the load frequency of two area system. The proposed NN-BFA based controller with two area system is illustrated in Figure 3 as follows:

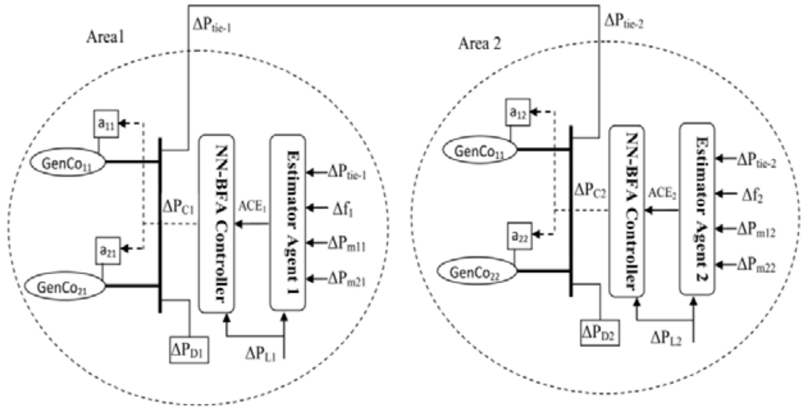

Figure 3. Two area system with proposed controller parameters.

In figure 3, estimator agent 1 and 2 are used to determine the change of value of area 1 and area 2 such as ΔP_{tie}, Δf, ΔP_m, and ΔP_L. From these change of parameters, error values are calculated which is applied as input of proposed LFC. As per the change of these input parameters, the control signal is generated which control the error of area 1 and 2. The detailed discussion of proposed NN-BFA control approach is explained in the following sections.

A. Proposed NN-BFA for load frequency control.

In the traditional BFA, the tumbling decision element Δ(i) is defined by the stochastic values. But these values are changed as per the variations of chemotactic step size C(i) so the solution is deviated in iteration and the convergence time is increased. In this paper, neural network (NN) is used to ensure the distribution of stochastic values with respect to the chemotactic step size. Here, the feed forward NN is used with back propagation training algorithm [38] [39]. Hence, the controller error, load changes, and speed changer position to be minimized and the stability of the interconnected power system are improved. The detailed explanation of neural network is presented in section 3.1. The flow chart of the proposed NN-BFA for gain tuning is illustrated in figure 4 as follows:

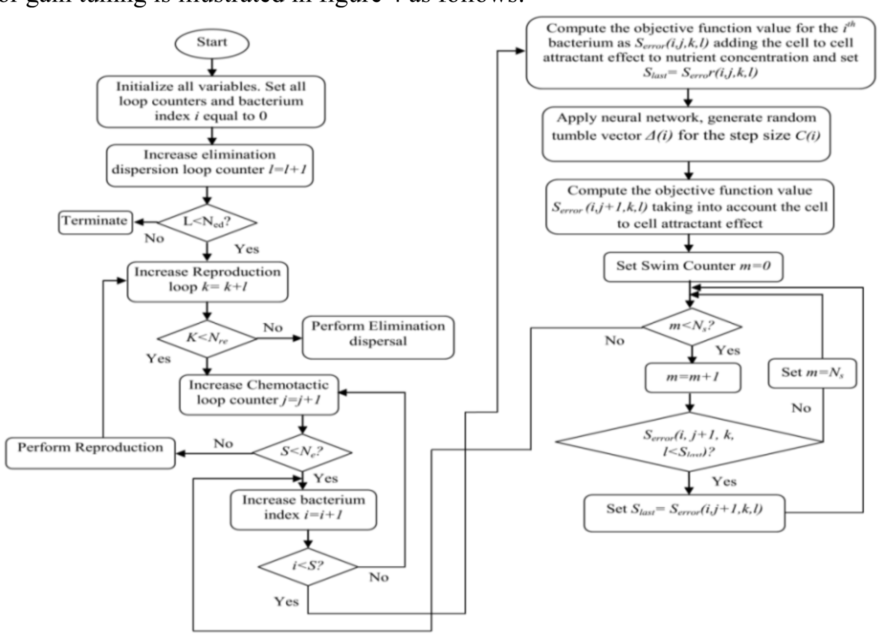

Figure 4: Flow chart for proposed NN-BFA.

The steps of proposed NN-BFA for tuning the controller gain is represented as follow,

Step 1: Initialization

In the first step, initialize the number of parameters to be optimized (P), number of bacteria (B), swimming length (N_S), number of iteration (N_C), maximum number of reproduction (N_{re}), maximum number of elimination and dispersal events (N_{ed}), probability of elimination and dispersal events (P_{ed}) and etc.

Step 2: Elimination

At the initial iteration, population chemotaxis, swarming, reproduction, and the elimination and dispersal loop of the bacterial model are set as zip values. From these, the algorithm is updated automatically to the optimized parameters. Count the loop, the elimination dispersal loop $(l = l + 1)$, the reproduction loop $(k = k + 1)$, and chemotaxis loop $(j = j + 1)$ respectively. $S_{error}(i, j, k, l)$ is the fitness function of i^{th} bacterium, S_{cc} is the cell to cell signaling in E. coli swarm, and θ^i is the movement of i^{th} bacterium. Then, compute $S_{error}(i, j, k, l)$ as follows:

$$S_{error}(i, j, k, l) = S_{error}(i, j, k, l) + S_{cc}(\theta^i(j, k, l), P(j, k, l))$$

Let, $S_{last} = S_{error}(i, j, k, l)$, then store the value and execute to find the better controller gains. S_{last} is the best fitness value.

Tumble: Using neural network (NN), generate the step size $C(i)$ random vector $\Delta(i) \in R^P$ with every aspect $\Delta_m(i),\ m = 1, 2, ..., p$, m is counter of swim length.

Move: Let, $\theta^i(j+1, k, l) = \theta^i(j, k, l) + \dfrac{C_{NN}(i)\Delta_{NN}(i)}{\sqrt{\Delta^T(i)\Delta_{NN}(i)}}$

Where, $C_{NN}(i)$ is the tested input of step size to NN, and $\Delta_{NN}(i)$ is the tested output of random vector which are the directions of the bacterium i.

Compute $S_{error}(i, j+1, k, l)$ and then,

$$S_{error}(i, j+1, k, l) = S_{error}(i, j+1, k, l) + S_{cc}(\theta^i(j+1, k, l), P(j+1, k, l))$$

Swim: Let $m = 0$ (oppose for swim length) while $m < N_s$

Let $m = m + 1$

If, $S_{error}(i, j+1, k, l) < S_{last}$, then $S_{last} = S_{error}(i, j+1, k, l)$,

Let $\theta^i(j+1, k, l) = \theta^i(j, k, l) + \dfrac{C_{NN}(i)\Delta_{NN}(i)}{\sqrt{\Delta^T(i)\Delta_{NN}(i)}}$ and use this $\theta^i(j+1, k, l)$ to compute the new $S_{error}(i, j+1, k, l)$. If, it is not satisfied, then select $m = N_S$. Go to the next bacterium $i+1$ if $i \neq B$ then process the next bacterium.

If $j < N_C$, go to chemotaxis loop three of Step 2. In this phase, maintain chemotaxis, because the existence of the bacteria is not over.

Step 3: Reproduction

Let, the healthy fitness of i^{th} bacterium is $S^i_{health} = \sum_{j=1}^{N_C+1} S_{error}(i, j, k, l)$ and sort the health bacterium i as per the test input value $C_{NN}(i)$ and in the order of ascending cost S_{health}.

Then, the number of bacteria reproduction (B_r) bacteria with the uppermost S health values die and the other B_r bacteria by means of the best values divide.
If $k < N_{re}$, go to reproduction loop (2) of step 2. On this reproduction case, if the solution is not reached, then start the next generation in the chemo tactic loop.

Step 4: Elimination-dispersal
In favor of $i = 1, 2, ..., B$, with possibility p_{ed}, eliminate and go away from every bacterium. If a bacterium is eliminated, just go away from one to a random position on the optimization field.
If $1 < N_{ed}$, then go to the exclusion dispersal loop $(l = l + 1)$ of step 2. Otherwise stop.
From the output of NN based algorithm, the optimal PID controller gains are calculated and the area control error is tuned

B. Explanation of NN

In this section, the explanation of NN is presented since which ensure the distribution of stochastic value with respective to the chemo tactic step size. Here, $C_{NN}(i)$ is the input of step size, and $\Delta_{NN}(i)$ is the output of random vector which depends on the direction of the bacterium i. The structure of network is given in figure 3. The input training data and the output training data are to the network is represented by equation (6) and (7) as follow,

Input data, $C_{NN}(i) = \left[C_{NN}^{(1)}(i), C_{NN}^{(2)}(i), C_{NN}^{(3)}(i), ...C_{NN}^{(n)}(i)\right]$ (6)

Target data, $\Delta_{NN}(i) = \left[\Delta_{NN}^{(1)}(i), \Delta_{NN}^{(2)}(i), \Delta_{NN}^{(3)}(i), ...\Delta_{NN}^{(n)}(i)\right]$ (7)

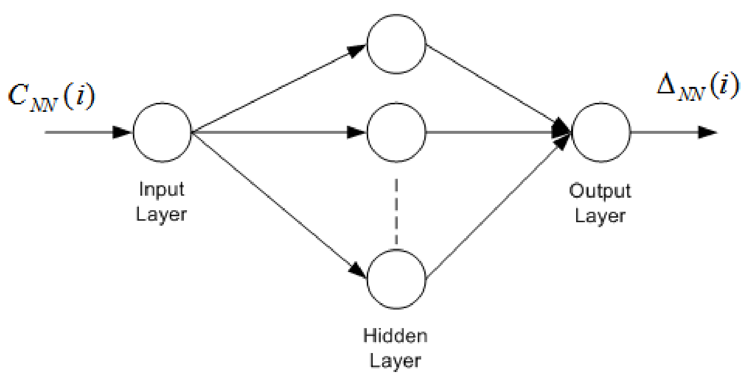

Figure 5. Overview of Neural Network.

The training steps of Back Propagation (BP) training algorithm are explained in below,
Step 1: Define the input, output and weight for each neuron. Here, $C_{NN}(i)$ is the input of the network and $\Delta_{NN}(i)$ is the output of the network.

Step 2: These data sets are given to the classifier and determine the BP error as follows,

$$BP_{error} = \Delta_{NN}^{tar}(i) - \Delta_{NN}^{out}(i) \quad (8)$$

Equation (8), $\Delta_{NN}^{tar}(i)$ is the target output and $\Delta_{NN}^{out}(i)$ is the output of the network.

Step 3: The output of the network is calculated as,

$$\Delta_{NN}^{out}(i) = \alpha + \sum_{n=1}^{N} w_{2n1}\, \Delta_{NN}^{(n)}(i) \tag{9}$$

$$\Delta_{NN}^{(n)}(i) = \frac{1}{1 + \exp\left\{-w_{1n}\, \Delta_{NN}^{tar}(i)\right\}} \tag{10}$$

The equations (9) and (10) are represented the activation function of output layer and hidden layer respectively.

Step 4: Changing the weights of neurons by $w_{new} = w_{old} + \Delta w$, where, Δw is the change in weight, which can be calculated as,

$$\Delta w = \delta . \Delta_{NN}^{out}(i) . BP_{error} \tag{11}$$

where, δ is the learning rate which varies from 1/5 to 2.5/5.

Step 5: Repeat the process from step 2, until BP_{error} gets minimized to a least value i.e,
$BP_{error} < 0.1$.

The NN will be suitable for giving the tumbling decision element $\Delta_{NN}^{out}(i)$ values respect to the input step size.

4. Results and Analysis

Initially, the two area interconnected power system model was implemented with the PID controller in MATLAB/Simulink. Then, the BFA and the NN-BFA were implemented for tuning the K_P, K_I, and K_D gains of the PID controller. In order to estimate the performance of the proposed tuning controller, the simulation results are compared with those of the PID, BFA-PID, and the NN-BFA-NN controllers. The load frequency control performance of the proposed technique is evaluated with two step and load perturbation condition on area 1 and 2 respectively. The implementation parameters of proposed tuning technique are illustrated in Table 1. The optimal tuning controller gains obtained by the BFA-PID and the NN-BFA-PID are given in table 2.

Table 1. Implementation parameters of proposed technique.

Dimension of search space =3
Number of bacteria = 10
Length of swim = 4
Number of reproduction steps = 4
Elimination-dispersal events = 2
Number of hidden layer = 20

Table 2. Optimal controller gain by different technique.

Optimal controller gain	**PID controller**	**BFA-PID controller**	**NN-BFA-PID controller**
Proportional K_P	0.1000	0.0891	0.1881
Integral K_I	0.5000	0.5163	0.4158
Derivative K_D	0.9000	0.0693	0.1985

The effectiveness of the proposed method is analyzed with the performance named as changes in frequency of area 1 ($\Delta\omega_1$) and area 2 ($\Delta\omega_2$), changes in tie line power P_{tie}, and changes in area of control error ACE1 and ACE2 respectively. The performance analysis is performed in two ways which are the step increases in load demand of area 1 and area 2. The step change values are used from the ranges 0.00001 to the required level. Under the step change condition, the load frequency of the system is varied from the desired level. Thus, the system characteristics are affected in their actual values such as tie line power, area control criteria and etc. The controller is used to tune the system performance to their desired level and the controller gains are addressed by the both methods which are presented in Table I.

Step increase in load demand of area 1.

In the first case, the load demand value is changed from the actual value to 0.00001 in area 1. In this condition, the change in frequency and the control error of area 1 and 2 of the proposed controllers are evaluated. The evaluated results are compared with those of the traditional PID controller and the BFA-PID controller. The comparison performance of changes in frequency ($\Delta\omega_1$) of area 1 and 2, the changes in area of control error ACE 1 and ACE 2, and the changes in tie line power are illustrated in Figure 6, 7, 8, 9, and 10 respectively. In Figure 6 and 7, the setting time and overshoot are reduced by the proposed tuning controller. It reaches the desired level within 4 seconds, but the PID and the BFA-PID controllers take high time duration to reach their level. The control area error and the tie line power are affected by the PID controller because of the high setting time, the intolerable oscillation and the delay in system stability. When compared with BFA, the damping characteristics of power system are improved more effectively by the proposed controller. However, the stability of the system is preserved and the power system oscillations are reduced and concealed with the appliance of the proposed controller.

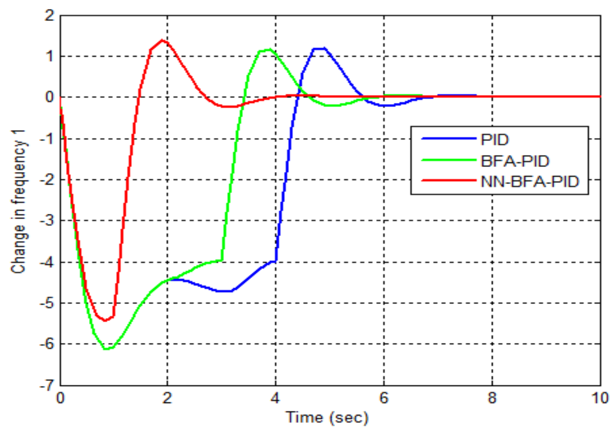

Figure 6. Change in frequency ($\Delta\omega_1$) of area 1.

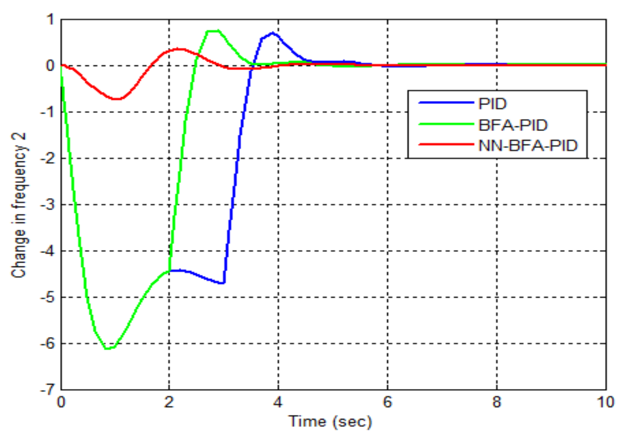

Figure 7. Change in frequency ($\Delta\omega_2$) of area 2.

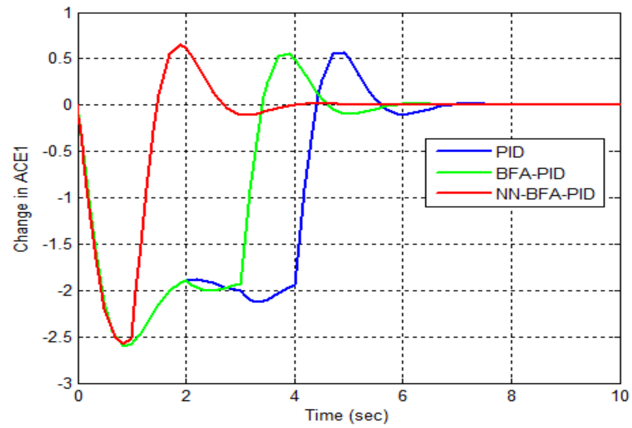

Figure 8. Change in area of control error (ACE) 1.

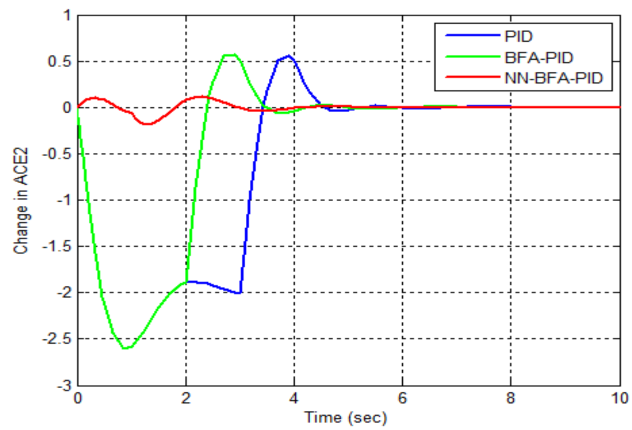

Figure 9. Change in area of control error (ACE) 2.

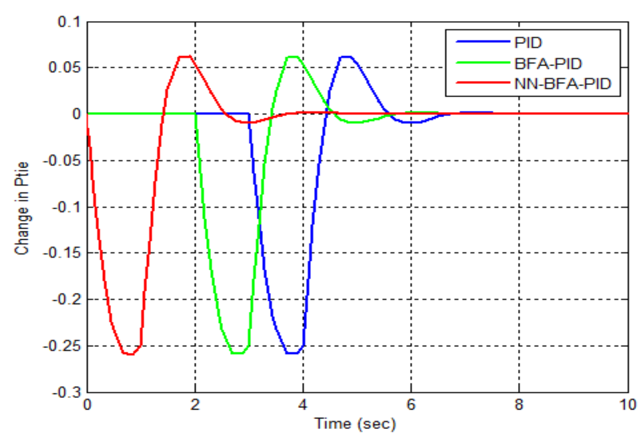

Figure 10. Change in tie line power signal of closed loop system.

Step increase in the demand of area 2

Here, the load demand value is changed from the actual value to 0.00001 in area 2 and the demand values of area 1 are maintained at their actual levels. Under this condition, the changes in frequency and the control error of area 1 and 2 of the proposed controllers are evaluated. When we change the load demand of area 2, the power system characteristics of area 1 are also affected which can be visualized from the evaluated responses, which are compared with the traditional PID controller and the BFA-PID controller, and the effectiveness is analyzed. The comparison performance of the changes in frequency ($\Delta\omega_1$) of area 1 and 2, the changes in area of control error ACE 1 and ACE 2, and the changes in tie line power are illustrated in figure 11, 12, 13, 14, and 15 correspondingly. In the illustrated characteristics, the setting time and overshoot are increased by the traditional controllers to undesirable level.

The PID and BFA-PID controllers take high setting time to reduce the system characteristics variation. The traditional controllers are settled in the time region of 4 to 6 seconds, but the proposed controller reaches the desired level in the time region of 2 to 4 seconds. The control area error and the tie line power are affected in the PID controller from the high setting time, the intolerable oscillation and the delay in system stability. The overshoot of the tie line power is changed to positively high scale which can be observed from figure 14. While compared with the BFA-PID controller, the power system damping characteristics are enhanced effectively by NN-BFA-PID. Moreover, the proposed controller reaches the change to zero level that is stable and power system oscillations are minimized and concealed with the application of the proposed controller. The time taken to reach the transient steady state level of the proposed controller is minimal.

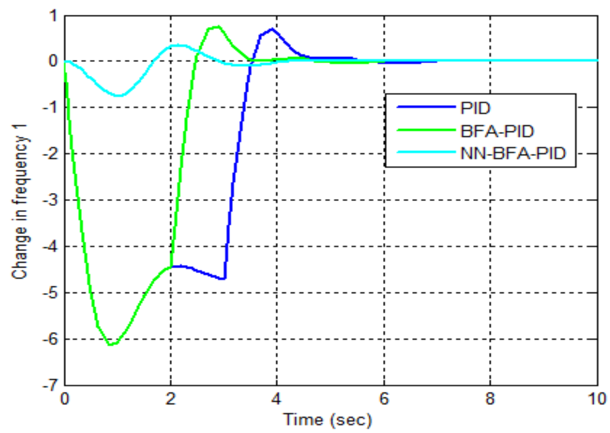

Figure 11. Change in frequency ($\Delta\omega_1$) of area 1.

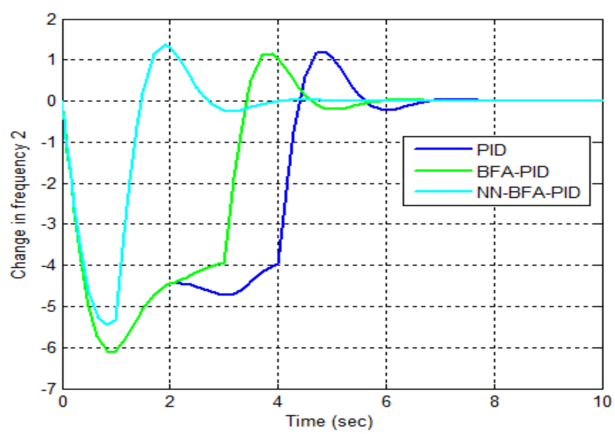

Figure 12. Change in frequency ($\Delta\omega_2$) of area 2.

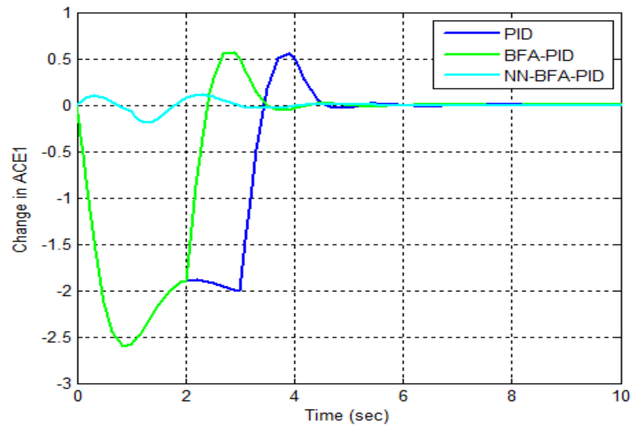

Figure 13. Change in area of control error (ACE) 1.

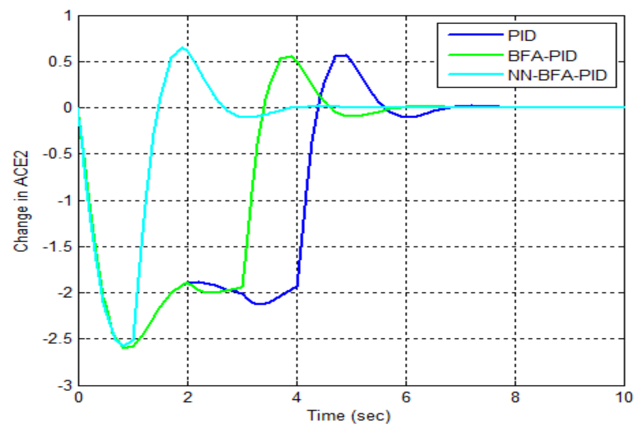

Figure 14. Change in area of control error (ACE) 2.

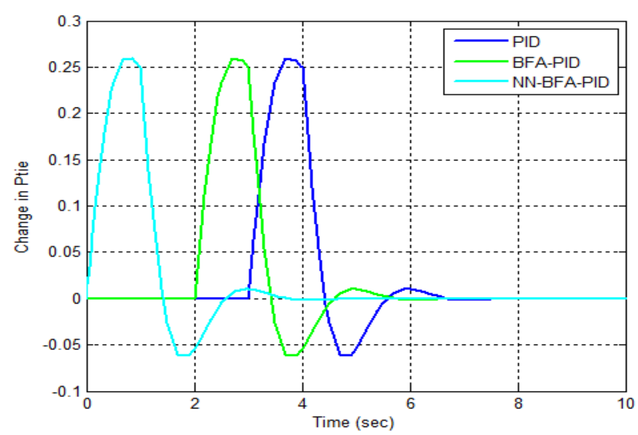

Figure 15. Change in tie line power signal of closed loop system.

5. Conclusion

The proposed load frequency controller was implemented and the performance was tested with that of the two area system. The performance of the proposed controller was compared with those of the traditional PID controller and the BFA-PID controller. The effectiveness of the proposed controller was analyzed in two ways. These steps increased the load demand of area 1 and area 2. From the analysis, the settling time of PID and BFA-PID controllers was reached in the time region of 4 to 6 seconds, but the proposed controller reached the desired level within the time region of 2 to 4 seconds. The setting time and overshoot were reduced and the stability of the system was thus maintained effectively by proposed controller.

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