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Load Frequency Control of A Multi-Area Power System

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ABSTRACT: Load Frequency Control (LFC) of a multi-area power systems is developed based on the Bacteria Foraging Optimization Algorithm (BFOA). Variations in load bring about drifts in frequency and voltage which in turn leads to generation loss owing to the line tripping and also blackouts. These drifts might be reduced to the smallest possible value by automatic generation control (AGC) which constitutes of two sections viz load frequency control (LFC) along with automatic voltage regulation (AVR). LFCs for each area are designed based on availability of frequency deviation of each area and tie-line power deviation between areas. Several important parameters of ALFC like integral controller gains (KIi), parameters for governor speed regulation (Ri) as well as parameters for frequency bias (Bi) are being optimized by using an optimization technique that is Bacteria Foraging Optimization Algorithm (BFOA) because using DIAFLC simulation has some demerits which has insisted on using BFOA for obtaining the desired values of the different parameters. In the presence of parameter uncertainties and unknown saturation and dead band of GRC and GDB which grants not only the best dynamic response for the system but also permits us to show the zero steady state frequency and tie line power deviation. Simulation results for a real three-area power system prove the effectiveness of the proposed LFC and show its superiority over a classical PID controller,DIAFLC Controller and a type-2 fuzzy controller.

KEYWORDS: BFOA,GDB, GRC, load frequency control (LFC),multi-area.

I .INTRODUCTION

Bacterial Foraging Optimization Algorithmic Program (BFOA) could be a Global Optimization Algorithmic Program for Distributed Control, Management and Optimization. Each bacterium looks around for nutrients in order to make the most of energy acquired per unit time. Individual bacterium simultaneously keeps up a correspondence with others by delivering signals. An individual bacterium will take foraging judgment after taking into consideration two prior factors. The process when a bacterium is all set for finding the nutrients with small steps is named as chemo taxis and principle concept of BFOA is chemo tactic locomotion mimicking within the region of problem search for the virtual bacterium.

Bacteria discover the direction to food in the surroundings on the basis of the gradients of chemicals. Similarly, bacterium secretes attracting along with repellant chemicals into the surroundings and is able to discover one another in the similar way. Locomotion mechanisms with the help of flagella, bacterium is used to make it able to move about in their surroundings, sometimes going around wildly (tumbling and spinning), and rest of the times moving in a determined path (swimming). The bacterial cells are usually treated resembling mediators in particular surroundings, by means of their food perception and various other cells as a motivating factor to move about, and random tumbling as well as swimming movement on the way to relocate. On the basis of the cell-cell interactions, cells might swarm a source of food, and/or might directly repel or else ignore one another.

Bacterial Foraging Optimization Algorithmic program is being used for reducing a cost function. Bacterium cost is determined by means of its interaction with various other cells. Calculation of this interaction function is done by using the parameters such as: a given cell, attraction coefficients, repulsion coefficients, the cells number within the population, the dimensions number on a given position vector of cells, the total number of cells maintained within the population, the total elimination-dispersal steps number, the total reproduction steps number, the total chemo taxis steps

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number, the total swim steps for a given cell, a random direction vector with identical range of dimensions because the problem region, and also the cells probability of being subjected to elimination plus dispersal.

II DYNAMIC MODEL OF A MULTI-AREA POWER SYSTEMS

Consider a power system consisting of LFC areas; each area has a number of generators. All generators in one area are simplified as an equivalent generator unit. Moreover, each area is assumed to have a number of gas turbines of simple cycle and combined cycle types and a number of steam turbines of reheat type. Without loss of generality, it is assumed that the controller to be proposed is installed to the gas turbines. While the steam turbines have no control on the reference set-point. The nonlinearities of the GRC and the GDB are incorporated in the model as nonlinear functions $\bar{v}_i(\Delta P_{t1i}, \Delta P_{g1i}), and\ \beta_i(\Delta P_{g1i})$ respectively. The block diagram of the LFC area in a multi-area system is shown in Fig 1

The dynamic model of each area can be written as:

$$\dot{\bar{x}}_i = \bar{A}_{ii}\,\bar{x}_i + \bar{B}_i\,\bar{u}_i + \bar{E}_i\Delta\bar{r}_i + \sum_{j=1}^{N}\bar{A}_{ij}\,\bar{x}_j + \bar{g}_{1i} + \bar{g}_{2i} - \bar{F}_i\Delta P_{di} \qquad (1)$$

$$y_i = \bar{C}_i\,\bar{x}_i \qquad (2)$$

where the control area matrices are given by

$$\bar{A}_{ij} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -2\pi T_{ij} & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$\bar{B}_i = [0 \;\; 0 \;\; \frac{1}{T_{g1i}} \;\; 0 \;\; 0 \;\; 0 \;\; 0]^T$$

$$\bar{F}_i = [\frac{1}{M_i} \;\; 0 \;\; 0 \;\; 0 \;\; 0 \;\; 0 \;\; 0]^T$$

$$\bar{E}_i = [0 \;\; 0 \;\; 0 \;\; 0 \;\; 0 \;\; 1 \;\; 0]^T$$

$$\bar{C}_i = [1 \;\; 0 \;\; 0 \;\; 0 \;\; 0 \;\; 0 \;\; 0]$$

$$\bar{g}_{1i} = \frac{1}{M}\begin{bmatrix} \bar{v}_i\left(\bar{x}_i\right) & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}^T$$

and $\bar{x}_i$ and $\bar{A}_{ii}$, shown at the bottom of the following $\bar{g}_{2i} = (1/T_{t1i})[0\,\bar{\beta}_i(\bar{x}_i) \;\; 0 \;\; 0 \;\; 0 \;\; 0 \;\; 0]^T$ and $\Delta\bar{r}_i$ is the change in reference set-point of the steam turbine (assumed zero), is the load change, $T_{ij} = T_{ji}$, and $\alpha = (-K_{ri}/T_{g2i}) + (1/T_{ri}))$ .The parameters of each control area, the tie-line power between each area, and the

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functions $\overline{v}_i(x_2, x_3)$ and $\beta_i(x_3)$ are assumed unknown. To facilitate the design of a local model (1) is transformed to the controller canonical from as

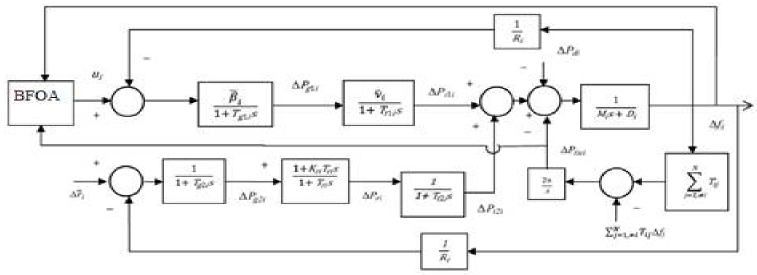

Fig.1: Dynamic model of the i[th] area in a multi-area power system

$$\dot{x}_i = A_{ii}x_i + B_iu_i + \sum_{j=1,\, j\neq 1}^{N} A_{ij}x_j + g_{1i}(x_i) + g_{2i}(x_i) - F\square P_{di} \qquad (3)$$

$$y_i = C_i x_i \qquad (4)$$

where $A_{ii} = S_i^{-1}\overline{A}_{ii}\,S_i, B_i = S_i^{-1}\overline{B}_i, F_i = S_i^{-1}\overline{F}_i, A_{ij} = S_i^{-1}\overline{A}_{ij}, S_j, C_i = \overline{C}_i, S_i g_{1i} = S_i^{-1}\overline{g}_{1i}, \overline{g}_{2i} = S_i^{-1}\overline{g}_{2i}$ and S_i is the similarity transformation matrix.

Equation (3) can be written in the following form:

$$\dot{x}_i = A_{ii}x_i + B_iu_i + D_i(X) + G_{1i}(x_i) - F_i \qquad (5)$$

where $D_i^T(X) = [D_{1i}(X)......D_{7i}(X)]$ accounts for the interconnections between the i[th] area and other areas $G_{1i}^T(x_i) = [G_{11i}(x_i)......G_{71i}(x_i)]G_{2i}^T(x_i) = [G_{12i}(x_i)...G_{72i}(x_i)]$ represent the GRC and GDB non linearity's. $F_i^T(x_i) = [F_{1i} = F_{7i}]$ represents the load disturbance terms, and the vector $X = [x_1x_2.....x_N]$ is the composite state vector.

The i[th] isolated and undisturbed LFC area of the model (5) without consideration of GDB and GRC nonlinearities is given by

$$\dot{x}_i = A_{ii}x_i + B_iu_i \qquad (6)$$

where the transformed matrices A_{ii}, B_i and C_i have the forms

$$A_{ii} = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 1 \\ -a_{0i} & -a_{1i} & -a_{2i} & -a_{3i} & -a_{4i} & -a_{5i} & -a_{6i} \end{bmatrix}$$

$$B_i^T = [0 \;\; 0 \;\; 0 \;\; 0 \;\; 0 \;\; 0 \;\; 1]$$

$$C_i = [C_{0i} \;\; C_{1i} \;\; C_{2i} \;\; C_{3i} \;\; C_{4i} \;\; 0 \;\; 0]$$

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The entries of the last row of A_{ii} denoted by $a_i = [-a_{ji}],\ j = 0,.....6,$ and $i = 1,.......N$ are negative and dependent on system parameters.
The transfer function of (6) is given by

$$H_i(s) = \frac{c_{4i}s^4 + c_{3i}s^3 + c_{2i}s^2 + c_{1i}s + c_{0i}}{s^7 + a_{6i}s^6 + a_{5i}s^5 + a_{4i}s^4 + a_{3i}s^3 + a_{2i}s^2 + a_{1i}s + a_{0i}}$$
$$= \frac{N_i(s)}{D_i(s)} \tag{7}$$

Xi=[Δfi ΔPg1i ΔPt2i ΔPri ΔPtiei]

$$\bar{A}_{ii} = \begin{bmatrix} -\frac{D_i}{M_i} & \frac{1}{M_i} & 0 & \frac{1}{M_i} & 0 & 0 & -\frac{1}{M_i} \\ 0 & -\frac{1}{T_{t1i}} & \frac{1}{T_{t1i}} & 0 & 0 & 0 & 0 \\ -\frac{1}{R_iT_{g1i}} & 0 & -\frac{1}{T_{g1i}} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -\frac{1}{T_{t2i}} & \frac{1}{T_{t2i}} & 0 & 0 \\ -\frac{k}{R_iT_{g2i}} & 0 & 0 & 0 & -\frac{1}{T_{ri}} & \alpha & 0 \\ -\frac{1}{R_iT_{g2i}} & 0 & 0 & 0 & 0 & -\frac{1}{T_{g2i}} & 0 \\ \sum_{j=1,j\neq 1}^{N} 2\pi T & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Upon repetitive differentiation of (4) and using (6) until the input appears, one can obtain

$$\ddot{y}_i = C_iA_{ii}^3x_i + C_iA_{ii}^2B_iu_i \tag{8}$$

where $C_iA_{ii}^3x_i = c_{4i}a_ix_i + [0\ \ 0\ \ 0\ \ co_i\ \ c_{1i}\ \ c_{2i}\ \ c_{3i}]^T x_i$ and $C_iA_{ii}^2B_iu_i = c_{4i}u_i, c_{4_i} \neq 0.$ Equation (8) indicates that the relative degree of each subsystem is 3. This means that its zero dynamics is of order 4. In fact the poles of reciprocal of the polynomial $N_i(s)$ represents the zero dynamics which is stable provided that $c_{ki} > 0, k = 0,.....4.$
If the parameters of subsystem (4) and (6) are precisely known, the ideal local control can be written as

$$u_i^* = \frac{1}{c_{4i}}\left(\ddot{y}_{ri} + K_i^Te_i - C_iA_{ii}^3x_i\right) \tag{9}$$

where y_{ri} is a reference signal, assumed to have bounded derivatives (up to 3). The control law (9) will force the error vector $\underline{e}_i = [e_i\ \dot{e}_i\ \ddot{e}_i]^T$ to converge to zero where $e_i = y_{ri} - y_i$ provided $K_i = [K_{oi}K_{1i}K_{2i}]^T$ is chosen such that all of the roots of the characteristic equation $s^3 + K_{2i}s^2 + K_{1i}s + K_{0i} = 0$ are in the open left half of the S-plane.

III. BFO ALGORITHM

A: Parameters Initialization

- S = total sample number of the bacteria that is to be utilized for finding in the sample region.

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- P = total quantity of parameters to be optimized. Here either KI_i or (KI_i andR_i) or (KI_i , R_i andB_i) are optimized.
- S_s = length of swimming subsequent to which the tumbling takes place in a Chemotactic loop.
- S_c = iterations number in a chemo tactic loop.
- S_{re} = utmost number of steps of reproduction.
- S_{ed} = utmost number of elimination and dispersal action forced on the bacteria.
- P_{ed} = probability for the continuation of elimination as well as dispersal process.
- Each bacterium P has a location that is stated by the arbitrary quantities within the range of [-1, 1].
- Value of C(a) is considered to be fixed for simplification.
- Values of $d_{attract}, w_{attract}, h_{repelent}$ and $w_{repelent}$.

B: Optimization

Step-1: Elimination-dispersal loop: d=d+1

Step-2: Reproduction loop: c=c+1

Step-3: Chemo taxis loop: b=b+1

i. For a =1, 2,…S take a chemo tactic step for bacterium a and calculate fitness function, *J(a, b, c, d).*
Let,

$$J_{sw}(a,b,c,d) = J(a,b,c,d) + J_{cc}(\theta^a(b,c,d), P(b,c,d))$$

(i.e. insert on the cell-to cell attractant–repellant effect/profile for simulating the behavior of swarming)

Where,

$$J_{cc}(\theta, P(b,c,d)) = \sum_{a=1}^{S} J_{cc}^{a}(\theta, \theta^a(b,c,d))$$

$$= \sum_{a=1}^{S}[-d_{attract}\exp(-\omega_{attract}\sum_{m=1}^{p}(\theta^m - \theta_m^a)^2] + \sum_{a=1}^{S}[-h_{repelent}\exp(-\omega_{repelent}\sum_{m=1}^{p}(\theta^m - \theta_m^a)^2]$$

$J_{last} = J_{sw}(a,b,c,d)$ to preserve this quantity because we might get a improved cost through a run.

End for this loop

ii. For a = 1, 2,..S tumble/swim decision is taken.

- **Tumble:** The random vector $\Delta(a)$ is generated on [-1, 1].

Let

$$\theta^a(b+1,c,d) = \theta^a(b,c,d) + C(a)\frac{\Delta(a)}{\sqrt{\Delta^T(a)\Delta(a)}}$$

This gives us a step of size C (a) in the path of the tumble for *a-th* bacterium.
Calculate J (a, b + 1, c , d) and let

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$$J_{sw}(a,b+1,c,d) = J(a,b+1,c,d) + J_{cc}(\theta^{a}(b+1,c,d), P(b+1,c,d))$$

- **Swim:**
  Let *mswim*=0 (counter for swim length).
  While *mswim*< *Ss* (if haven't brought down excessively long).
  Let *mswim=mswim+1*.
  If Jsw (a, b + 1, c , d) =J*last* (if doing better), let J*last* = Jsw (a, b + 1, c , d) and
  Let

$$\theta^{a}(b+1,c,d) = \theta^{a}(b,c,d) + C(a)\frac{\Delta(a)}{\sqrt{\Delta^{T}(a)\Delta(a)}}$$

  And use this $\theta^{a}(b+1,c,d)$ to find the new $J(a,b+1,c,d)$
  Else, let $m_{swin} = S_{s}$

This Ends the while statement

iii. Go to the just succeeding bacterium (*a+1*) suppose $a \neq S$
(i.e., go to [ii] to continue with the successive bacterium).

Step-4: If *b* < *Sc* , proceed on to step 3 and carry on with the chemo taxis process since the lifetime of the bacteria isn't ended.

Step-5: **Reproduction**

i. For the known *c* and *d*, and for every *a* = 1,2,…, *S* , let

$$J_{health}^{a} = \sum_{b=1}^{S_c+1} J(a,b,c,d)$$

be the fitness of the bacterium *a* (a quantity of the number of nutrients it acquired during its lifespan moreover how efficient it was at overcoming toxic substances).

Arrange bacteria and also chemo tactic parameters *C* (*a*) in sort of ascending cost J_{health} (high cost gives low health).

ii. The $S_{r} = S/2$ bacterium with the maximum *J health* values die and the rest of the *Sr* bacteria possessing the best values divide (this method is performed by the group of bacteria that are being placed at the similar location where the parent was present).

Step-6: If $c < S_{re}$, proceed on to step 3 because we haven't reached the specified quantity of reproduction steps and therefore we begin the succeeding generation of the chemo tactic loop.

Step-7: Elimination-dispersal: For *a* = 1,2..., *S* possessing probability P_{ed} every bacterium is eliminated and dispersed so as to keep the quantity of bacteria present in the population to a constant value. During this process if a bacterium is removed then simply scatter a new one to any arbitrary position on the optimization domain.
When *d* = S_{ed} then move on to step 2 else end it.

Step-8: Obtain the optimized values of the parameters.

Step-9: Employ BFO for final updating of the various parameters as desired in the system

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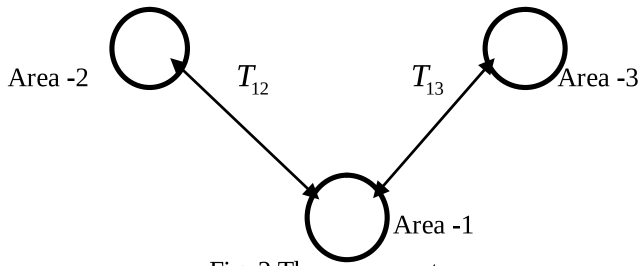

Fig .2 Three area system

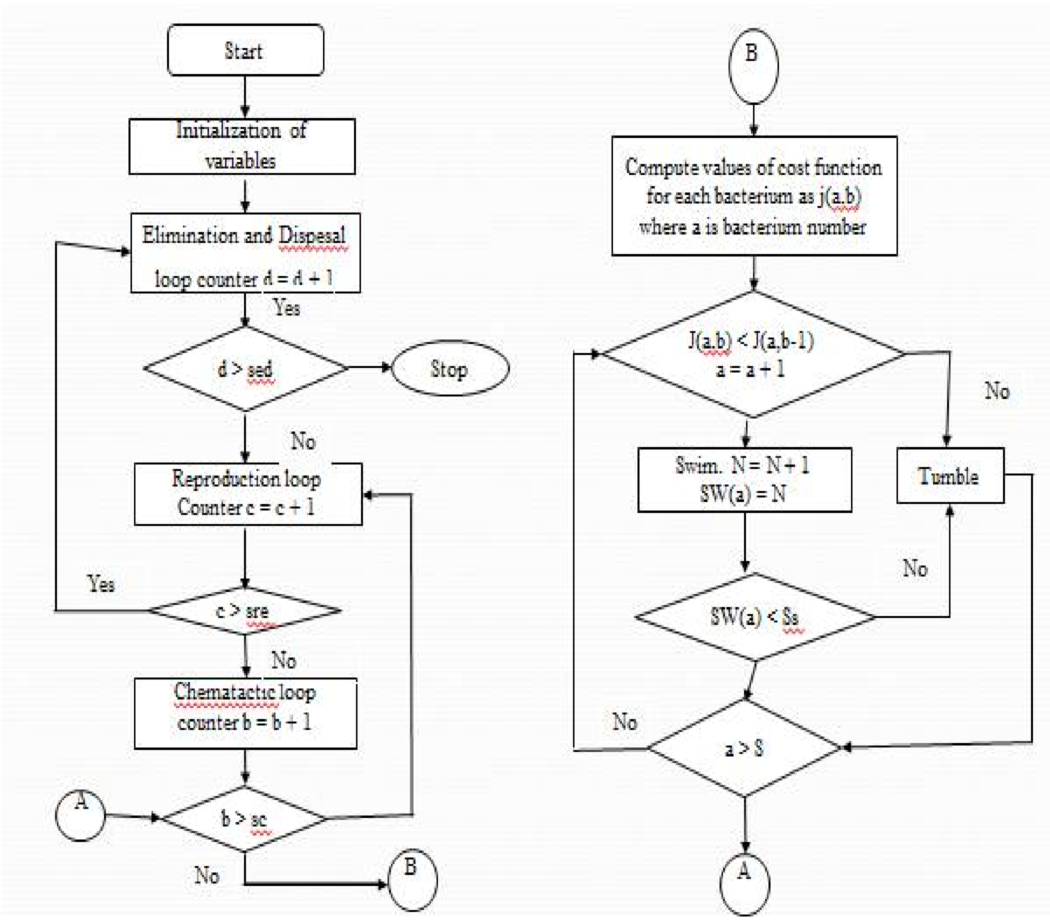

Fig.3 Flowchart of the Bacteria Foraging Algorithmic program

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Table I: System parameters

Parameter	Area-1	Area-2	Area-3
D	0.24	0.11	0.046
K_r	0.3	0.3	
M	167	89.5	23.25
R	0.04	0.04	0.04
T_{t1}	0.4	0.4	0.1
T_{g1}	0.1	0.1	0.4
T_{t2}	1.0	1.0	
T_{g2}	0.1	0.1	
T_{ri}	1.0	1.0	
$T_{12}=T_{21}$	8.4	8.4	
$T_{13}=T_{31}$	2.3		2.3

Table II: Controller Parameters

Area	DAFLC	PID
1	γ_1=50, $\gamma_2=2.5, Q$=1.5 I, $\rho=0.85, r=1$	K_p=64.8, K_I=5.02, K_D=62.7
2	γ_1=10, $\gamma_2=2.5$ Q=0.01 I, $\rho=0.85$ $r=1$	K_p=0.36, K_I=0.011, K_D=4.5
3	γ_1=25, Q=0.5 I, $\rho=0.85$ $r=1$	K_p=0.8, K_I=5.02, K_D=0.006

Table III: If–Then rules for the type-2 fuzzy controller

ACE	**N**	**Z**	**P**
N	P	N	N
Z	N	P	P
P	N	N	N

IV .SIMULATION RESULTS

A real three-area interconnected power system existing in the gulf region is considered as a simulation example to investigate the effectiveness of the proposed BFOAlogrithm.The three area power system is shown in fig.3.The system parameters are given table 1. It is assumed that no fuzzy control rules are available for the proposed BFOA.Comparisons between simulation results of the proposed BFOA and those of a PID classical controller, designed using Ziegler-Nichols method, and a type-2 fuzzy decentralized LFC(Type-2 Fuzzy) ,DIAFLC are carried out in the presence of GRC and GDB. The parameters of the DIAFLC and the PID controller are tabulated in Table II and the “If-then” rules for the Type-2 fuzzy controller are given in Table III.

Two different simulation cases are considered. In case I, the nominal parameters of the system are used, and two simulation tests are carried out, namely, a load disturbance of 300 MW (0.3 p,u,) is assumed to take place in area-1 (case I-A) and load disturbances of 0.3, 0.1, and 0.01 p.u. are assumed to occur in areas 1, 2, and 3, respectively (case I-B). The off-nominal parameters are considered in case II. In this case, two simulation sets of results are obtained. In the first set a mismatch of 50% in both the inertia constant and load damping coefficient is assumed(case II-A). The second set where the tie-line synchronizing power coefficient has amismatch of 50% is considered (case II-B). Simulation results of the frequency and the tie-line power deviations of area 1 for case I-A are shown in Figs. 4 and 5. Frequency and tie-line power deviations of area 1 for case I-B are shown in Figs. 6 and 7. Simulation results for cases II-A and II-B are given in Figs. 8–11, respectively.

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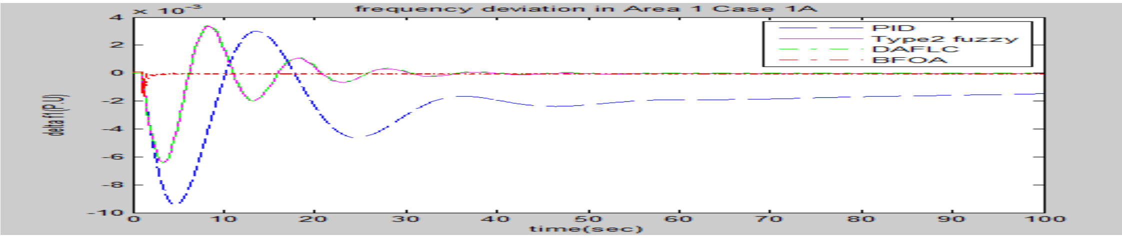

Fig. 4: Frequency deviation in area-1 (case I-A)

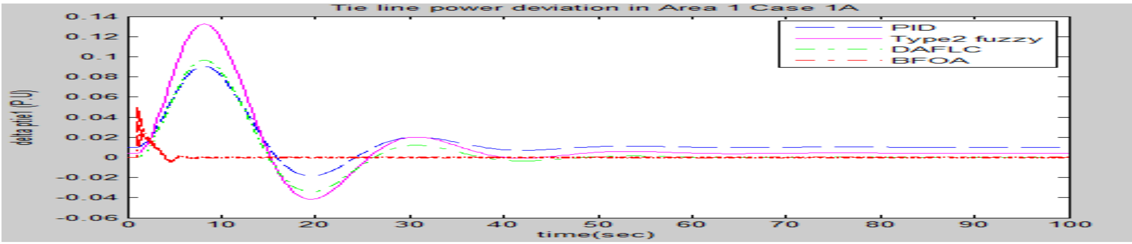

Fig. 5: Tie-line power deviation to area-1 (case I-A)

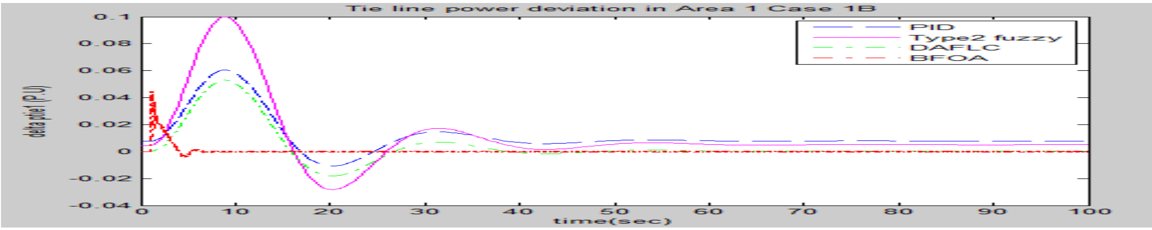

Fig. 6: Tie-line power deviation to area-1 (case I-B)

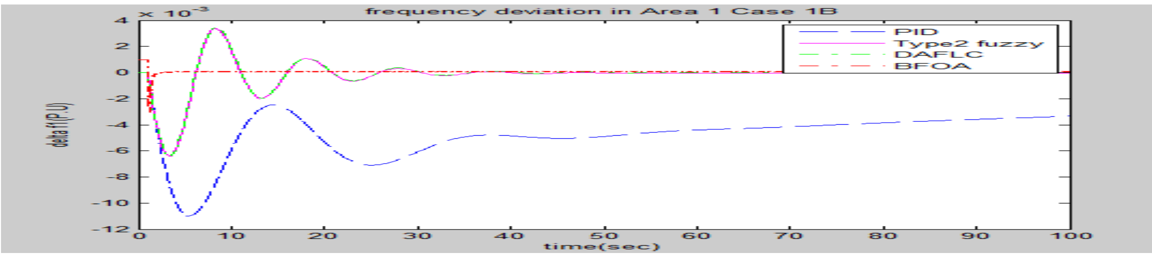

Fig .7: Frequency deviation in area-1 (case I-B)

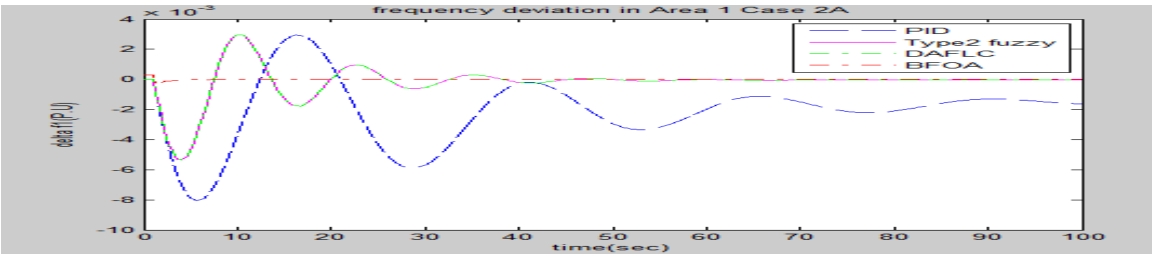

Fig. 8: Frequency deviation in area-1 (case II-A)

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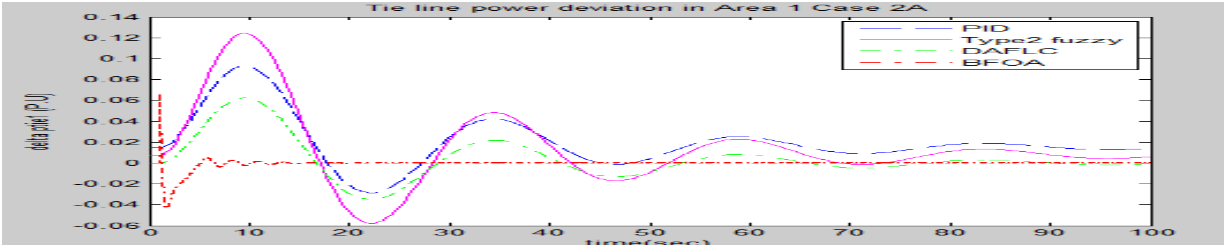

Fig. 9: Tie-line power deviations to area-1 (case II-A)

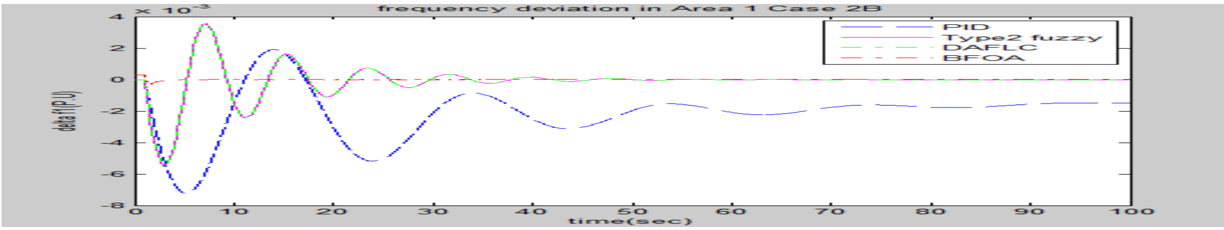

Fig.10. Frequency deviation in area-1 (case II-B)

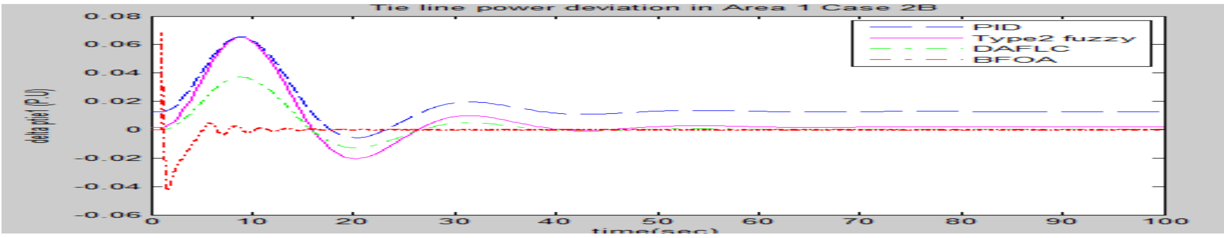

Fig.11. Tie-line power deviations to area-1 (case II-B)

A summary of simulation performance in terms of the steady-state $(|\Delta f_{1ss}|)$ and maximum overshoot($|\Delta f_{1ss}|)$ of frequency deviation for area 1 and the steady-state $(|\Delta P_{tie\,1ss}|)$ and maximum overshoot$(|\Delta P_{tie\,1max}|)$ of tie-line power deviation for area 1 of the three controller is shown in below tabular column.

Table 4: Performance comparison in terms of the steady state frequency deviation for area 1

$|\Delta f_{1ss}|$				
Case	BFOA	DAFLC	Type-2 Fuzzy	PID
Case 1A	0	0	0	9
Case 1B	0.000256	0.004497	0.044452	9.306719
Case 2A	0.0002	0.043837	0.000438	6.932696
Case 2B	0.000269	0.004388	0.004388	6.263454

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Table 5: Performance comparison in terms of the maximum overshoot frequency deviation for area 1

$\lvert\Delta f_{1max}\rvert$				
Case	BFOA	DAFLC	Type-2 Fuzzy	PID
Case 1A	1.678706	6.437442	6.434602	9.444541
Case 1B	3.071138	6.437442	6.431608	10.99111
Case 2A	0.356472	5.354731	5.354731	8.045088
Case 2B	0.348411	5.511364	5.511364	7.22221

Table 6: Performance comparison in terms of the steady state tie line power deviation for area 1

$\lvert\Delta P_{tie\,1ss}\rvert$				
Case	BFOA	DAFLC	Type-2 Fuzzy	PID
Case 1A	0	0	0	10
Case 1B	0.023727	0.302367	5.044261	7.808516
Case 2A	0.038948	0.638686	0.086975	15.79836
Case 2B	0.042464	0.211657	1.86284	12.80852

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Table 7: Performance comparison in terms of the maximum overshoot tie line power deviation for area 1

$\lvert\Delta P_{tie\,1max}\rvert$				
Case	BFOA	DAFLC	Type-2 Fuzzy	PID
Case 1A	55.69804	78.52357	104.6981	109.0605
Case 1B	49.40965	71.23198	89.7523	71.23198
Case 2A	11.01037	97.18646	182.2246	121.4831
Case 2B	11.13305	49.86239	85.47838	71.23198

It is clear that the BFOA achieves the LFC objectives even in the presence of parameter uncertainties and unknown saturation and dead band of GRC and GDB. It is worth-noting to mention that the advantage of the BFOA is that it does not need any set of "if-then" rules in contrast to the type-2 fuzzy controller and it can cope with parameter variation and the unknown nonlinearities. However, from the comparison table, $\lvert\Delta f_{1max}\rvert$and $\lvert\Delta P_{tie\,1max}\rvert$of the BFOA is higher than those of the PID, DIAFLCand Type-2 Fuzzy controller

V.CONCLUSION

Load frequency control of multi-area power system having unknown parameters. The proposed algorithm is developed using BFOA technique. Bacteria Foraging Optimization Algorithmic program to change the values of the various parameters present in the power system under investigation so it can cope up with the presence of parameter uncertainties and unknown saturation and dead band of GRC and GDB.. As a result of which the changes the frequency and also the tie line power is reduced and also the stability of the system is maintained. BF technique serves to be quite useful for obtaining the optimized values of the various parameters as compared to DIAFLC technique which is extremely tedious and time taking method. A realistic three-area power system is used as a validation example.Simulation results show that the developed BFOA is able to achieve the LFC objectives in terms of zero steady-state frequency and tie-line deviations. Superiority of the developed BFOA over a DIAFLC,Type-2 fuzzy and a classical PID controller is illustrated.

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