ISSN 2395-695X (Print)
ISSN 2395-695X (Online)
International Journal of Advanced Research in Biology Engineering Science and Technology (IJARBEST)
Vol. 2, Special Issue 15, March 2016

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# Bacterial Foraging Optimization Based Load Frequency Control of Interconnected Power Systems

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Abstract: This paper proposes a design of Bacterial Foraging Optimization (BFO) based optimal integral controller for the load- frequency control of two-area interconnected power systems. The importance of load frequency control is used to maintain the frequency constant as due to variations in load. The BFOA technique is used to optimize several important parameters in Load Frequency control (LFC) of an interconnected multi area – multi machine system such as Kp, Ki and compare its performance to establish its superiority over soft computational techniques like ACO and PSO. Comparison of convergence characteristics of BFO, PSO, ACO and Classical (Z-N) approach reveals that the BFO algorithm is quite faster in optimization, leading to reduction in computational burden and giving rise to minimal computer resource utilization. Simultaneous optimization of Kp and Ki parameters with BFOA technique which has never attempted in the past, provides better dynamic response of the power system.

*Keywords*: Bacterial Foraging Optimization Algorithm, Integral Controller, Ant Colony Optimization, Particle Swarm Optimization, Load-Frequency Control.

## 1. Introduction

Power systems are used to produce electrical power from natural or renewable energy. Load Frequency control (LFC) is really important in power systems to supply reliable and better electric power at consumer end. However, the consumers of the electric power vary the loads randomly and frequently. Change in load leads to adjustment of generation so that there is no power imbalance whereas controlling the power generation is a problem. To nullify the effects of the haphazard load changes and to keep the voltage as well as frequency within pre-specified values a control system is essential. The frequency is closely related to real power balance whereas voltage is related to reactive power. The real power and frequency control is referred to as load frequency control (LFC). If in a system there are changes in load then those changes will affect both frequency and bus voltages. LFC as the name signifies adjusts the power flow between different areas while holding the frequency constant. [1] LFC is actually a loop that regulates output in the range of megawatt and frequency of the generator. This consists of two loops i.e. primary and secondary loop. The problems of frequency control of interconnected areas are more important than those of single area systems. The problems of frequency control of interconnected areas are more important than those of single area systems.

The system frequency is mainly affected due to change in load while reactive power depends on change in voltage magnitude and is less sensitive to frequency. To keep the frequency constant by Proportional plus Integral controller is used which controls the turbines used for tuning the generators and also the steady state error of system frequency is reduced by tuning the controller gains [3]. Nowadays power system complex are being solved with the use of Computation such as Practical Swarm Optimizations [PSO] [4] Ant Colony Optimization [ACO], which are some of the heuristic techniques having immense capability of determining global optimum. [5] Classical approach based optimization for controller gains is a trial and error method and extremely time consuming when several parameters have to be optimized simultaneously and provides suboptimal result. Some authors have applied PSO to optimize controller gains more effectively and efficiently than the classical approach. Recent research has brought some improvements. [10], [11]. The Bacterial Foraging Optimization [BFO] shows how bacteria forage over a landscape of nutrients to perform parallel non gradient optimization. The BFO algorithm is a computational intelligence based technique that is not large affected by the size and non-linearity of the problem and can be convergence to the optimal solution in many problems where most analytical methods faith convergence. A more recent and powerful evolutionary computational technique "Bacterial Foraging" (BF) [12] is found to be user friendly and is adopted for simultaneous optimization of several parameters for both primary and secondary control loops of the governor.

The simulation results show that the dynamic performance of the system is improved by using the proposed controller. The organizations of this paper are as follows. In section 2, modelling of power system is described. In section 3 classical controller (Z-N) is described. In section 4 comparison of ACO and PSO is described. Overview of BFO is described in section 5. The output response of the system is investigated with the BFO Algorithm in section 6. Section 7 presents the simulations and comparison its results; finally a conclusion is discussed in section 8.

**2) Modelling of Two Area Power System**:
The connection between power system is made possible via Tie-line allows the flow of electric power between two areas. Area will obtain energy with the help of tie-lines from other areas, when load change occurs in that area. Hence load frequency control also needs to control the tie-line power exchange error. Tie-line power error are the integral of the frequency difference in between two areas.

Change in Tie-line power can be written mathematically as

$$\Delta P_{12}(s) = 2\pi T_{12}(\Delta f_1(s) - \Delta f_2(s)) \quad (1)$$

Where $\Delta P_{12}(s)$ = Change in tie-line power
$\Delta f_1(s)$ = frequency deviation in area 1
$\Delta f_2(s)$ = frequency deviation in area 2

Control area of each area consists of linear combination of tie line flows and frequency.

Area Control Error can be represented as

$$ACE_i = \sum_{i=1}^{k} \Delta P_{tie,i,j} + B_i \Delta f_i \quad (2)$$

Where $B_i$ = Frequency Bias factor of area i.

$\Delta f_i$ = frequency deviation in area i

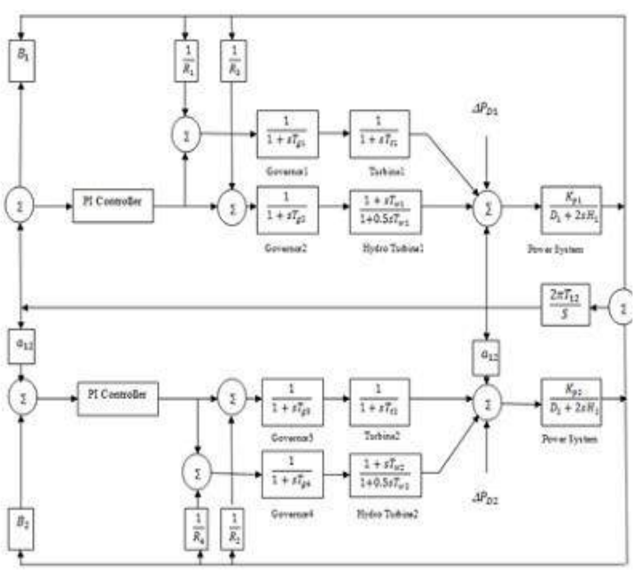



Figure 1 – Two Area Interconnected Power System

**3) Ziegler–Nichols tuning Method for PI controller:**
The gains of PI controller can be tuned by conventional ZN method; this is one of popular classical tuning method for PI controller. ZN tuning method is preferable for very complex and bulky system those mathematical modeling is tedious task. The ZN method is a heuristic approach to tune PI Controller. This method is based on selection of proper value of proportional gain at which sustained oscillation occurs, from which ultimate gain and oscillation period are obtained. Once for any system value of ultimate gain and oscillation period obtained then gains value of PI controller also calculated

**4. a) Ant Colony Optimization:**
The ant colony optimization algorithm (ACO) is a probabilistic technique for solving computational problems which can be reduced for finding good paths through graphs. In the natural world, ants (initially) wander randomly, and upon finding food return to their colony while laying down pheromone trails. If other ants find such a path, they are likely not to keep travelling at random, but to instead follow the trail, returning and reinforcing it if they eventually find food. Over time, however, the pheromone trail starts to evaporate, thus reducing its attractive strength. The more time it takes for an ant to travel down the path and back again, the more time the pheromones have to evaporate. A short path, by comparison, gets marched over more frequently, and thus the pheromone density becomes higher on shorter paths than longer ones the behavior of real ants in searching the source of food, it proves also that shorter paths have larger pheromone concentrations, so more ants tend to travel in these paths.

Pheromone Updation equation:

$$T_{xy} = (1-\rho)T_{xy} + \sum_k \Delta T_{xy}^k \quad (3)$$

Where $T_{xy}$ = is the amount of pheromone deposited for a state transition xy.
$\rho$ is the pheromone evaporation coefficient
$\Delta T_{xy}^k$ is the amount of pheromone deposited by K$^{th}$ ant

**4. b) Particle Swarm Optimization:**
Particle swarm optimization (PSO), originated by James Kenndy and R.C Eberhart in 1995. It is a stochastic (connection of random variables) evolutionary computation method used to explore search space. This technique is based on swarm's intelligence and movement. As this is based on swarm behavior of population based technique. The bird is generally follows the shortest path for food searching. Based on this behavior, this algorithm is developed. It uses a number of particles where every particle is considered as a point in N-dimensional space. It is well described by the concept of social interaction because each particle search in a particular direction and by interaction bird with best location so far and then tries to reach that location by adjusting their velocity this requires intelligence.
The two main equations of PSO algorithm as follows:

Velocity Modification equation:

$$v_i^{k+1} = wV_i^k + c_1 rand_1 \times \left(pbest_i - S_i^k\right) + c_2 rand_2 \times gbest_i - S_i^k \qquad (4)$$

Where $V_i^k$ = Velocity of agent I at iteration k
w = weighing function
$c_i$ = weighing factor
$rand_i$ = random number between 0 and 1
pbesti = p – best agent i
$s_i^k$ = current position of agent I at iteration k
$gbest_i$ = g – best of the group

Position Modification equation:

$$S_i^{k+1} = S_i^k + V_i^{k=1} \qquad (5)$$

Where $S_i^{k+1}$, $S_i^k$ are Modified and Current Search points respectively.

$V_i^{k=1}$ = Modified Velocity

**5) Bacterial Foraging Optimization Technique:**

A recent evolutionary computation technique, called BF scheme has been proposed by Kevin M. Possino in which the number of parameters that are used for searching the total space is much higher compared to those of PSO and ACO. In BF, the foraging (the methods of locating, handling, ingesting food) behavior of E.coli bacteria present in our intestine is mimicked. The control system of these bacteria that dictates how foraging should proceed can be subdivided into four sections namely chemotaxis, swarming, reproduction and elimination and dispersal. The brief descriptions of these operations are as follows.

(1) Chemotaxis:
Chemotaxis process is the characteristics of movement of bacteria in search of food and consists of two processes namely swimming and tumbling .A bacterium is said to be swimming if it moves in a predefined direction, and tumbling if it starts moving in an altogether different direction. In particular where represents the $i^{th}$ bacterium at $i^{th}$ chemotactic, $i^{th}$ reproductive and $i^{th}$ elimination and dispersal step.

(2) Swarming:
During the process of reaching towards the best food location it is always desired that the bacterium which has searched the optimum path should try to provide an attraction signal to other bacteria so that they swarm together to reach the desired location. In this process, the bacteria congregate into groups and hence move as concentric patterns of groups with high bacterial density,
Mathematically swarming behavior can be represented by

$$Jcc\left(\theta, \theta^i(j,k,l)\right) = \sum_{i=1}^{s} J_{cc}^i \left(\theta, \theta^i (j,k,l)\right)$$
$$= \sum_{i=1}^{s} \left[-d_{attract}\, exp\left(-w_{attract} \sum_{m=1}^{p} (\theta_m - \theta_m^i)^2\right)\right]$$
$$+ \sum_{i=1}^{s} \left[-h_{repelent}\, exp\left(-w_{repelent} \sum_{m=1}^{p} (\theta_m - \theta_m^i)^2\right)\right] \qquad (6)$$

Where
$Jcc\left(\theta, \theta^i(j,k,l)\right)$ is the cost function value to be added to the actual cost function to be minimized to present a time varying cost function.
"S" is the total number of bacteria and "p" is the number of parameters to be optimized which are present in each bacterium.
$d_{attract}$, $w_{attract}$, $h_{repelent}$ and $w_{repelent}$ are different coefficients that are to be chosen properly

(3) Reproduction:
In this step, population members who have had sufficient nutrients will reproduce and the least healthy bacteria will die. The healthier population replaces unhealthy bacteria which gets eliminated wing to their poorer foraging abilities. This makes the population of bacteria constant in the evolution process.

(4) Elimination and dispersal:
It is possible that in the local environment the life of a population of bacteria changes either gradually (e.g., via consumption of nutrients) or suddenly due to some other influence. Events can occur such that all the bacteria in a region are killed or a group is dispersed into a new part of the environment. They have the effect of possibly destroying the chemotactic progress, but they have the effect of assisting in chemotaxis, since dispersal may place bacteria near good food sources. From a board perspective, elimination and dispersal are parts of the population – level long distance motile behavior.

**6) Bacterial Foraging Algorithm:**
In case of BFO technique each bacterium is assigned with a set of variable to be optimized and are assigned with random values within the universe of discourse defined through upper and lower limit between optimum values is likely to fall. In the proposed method integral gain $K_{Ii}$ (i=1, 2) scheduling, each bacterium is allowed to take all possible values within the range and the cost objective function [J] is represented as

$$J = \int_0^T \{(\Delta f_i)^2 + (\Delta P_{tie\, i-j})^2\} dt \qquad (7)$$

Where T is the simulation time.
In this study convergence characteristics and is implemented as follows.
Step 1- Initialization

a. Number of parameter (p) to be optimized.
b. Number of bacterial (S) to be used for searching the total region.
c. Swimming length (Ns), after which tumbling of bacteria will be undertaken in a chemotcatic loop
d. Nc, the number of iteration to be undertaken in a chemotactic loop (Nc>Ns)
e. Nre ,the maximum number of reproduction to be undertaken
f. Ned, the maximum number of elimination and dispersal events to be imposed over bacteria.
g. $P_{ed}$, the probability with which the elimination and dispersal will continue.
h. The location of each bacterium P (1-p, 1-s, 1) which is specified by random numbers within [-1, 1].

i. The value of C (i), which is assumed to be constant in our case for all bacteria to simplify the design strategy.

j. The value of $d_{attract}$ ,$w_{attract}$ ,$h_{repelent}$ and $w_{repelent}$ .it is to be noted here that the value of $d_{attract}$ and $h_{repelent}$ must be same so that the penalty imposed on the cost function through "Jcc"" well be "0"" when all the bacteria will have same value , i.e. ,they have converged

Step - 2 Iterative algorithms for optimization:

This section models the bacterial population chemotaxis is swarming, reproduction, elimination, and dispersal (initially j=k=l=0).for the algorithm updating in updating of `P".

(1) Elimination –dispersal loop: l=l+1

(2) Reproduction loop: k = k + 1

(3) Chemotaxis loop: j = j + 1

(a) For i =1, 2…S, calculate cost for each bacterium I as follows.

- Compute value of cost J (i, j, k, l) ,

Let $J_{sw}$ (i, j, k, l) = J (i, j, k, l) + J cc ($\Theta_i$ (j, k, l), P (j, k, l))

- Let $J_{last}$ = $J_{sw}$ (i, j, k, l) to save this value since we may find a better cost via a run
- End of for loop.

(b) For i=1, 2….S take the tumbling / swimming decision

- Tumble: generate a random vector Δ(i) € $R^p$ with each element Δm(i)m=1, 2, ……, p, a random number on [-1, 1]
- Move: let

$$\theta^i(j+1,k,l) = \theta^i(j,k,l) + C(i)\frac{\Delta(i)}{\sqrt{\Delta^T(i)\Delta(i)}} \qquad (7)$$

Fixed step size in the direction of tumble for bacterium i is considered

Compute J (i, j+1, k, l) and then let $J_{sw}$ (i, j+1, k, l) = J (i, j+1, k, l) + $J_{cc}$ ($\theta^i$(j+1, k, l), P (j+1, k, l))

Swim:

i) Let m=0; (counter for swim length).

ii) While m<Ns (have not climbed down too long)

- Let m=m+1
- If $J_{sw}$ (I, j+1, k, l) < $J_{last}$ (if doing better), let $J_{last}$ = $J_{sw}$ (i, j+1, k, l) and let

$$\theta^i(j+1,k,l) = \theta^i(j,k,l) + C(i)\frac{\Delta(i)}{\sqrt{\Delta^T(i)\Delta(i)}}$$

And use this $\theta^i(j+1,k,l)$ to compute the new J (i, j+1, k, l).

Else, let m=Ns. (This is the end of while statement)

c) Next bacterium (i+1) is selected if i ≠S (i.e., go to b) to process the next bacterium

4) If j< Nc, go to step 3. In this case, chemotaxis is continued since the life of the bacteria is not over

5) Reproduction:

a) For the given k and l for each i=1, 2………S let

$J^i_{health}$ = min j € {1… Nc} ($J_{sw}$ (i, j+1, k, l)} be the health of the bacterium i (a measure of how many nutrients it got over its life time and how successful if was at avoiding noxious substance).Sort bacteria in order of ascending cost $J_{health}$ (higher cost means lower health).

b) The $S_r$ =S/2 bacteria with highest $J_{health}$ valves die and other $S_r$ bacteria with the best value split (and the copies that are placed at the same location as their parent)

6) It k<Nre, go to 2; in this case ,as the number of specified reproduction steps have not been reached ,so we start the next generation in the chemotactic loop.

7) Elimination –dispersal: for i = 1, 2… S with probability $P_{ed}$, eliminates and disperses each bacterium (this keeps the number of bacteria in the population constant) to a random location on the optimization domain.

## Table 1 – Parameter values for BFO Algorithm

| Sl. No | Parameters | Value |
|---|---|---|
| 1 | Number of Bacterium (s) | 10 |
| 2 | Swimming length ($N_s$) | 4 |
| 3 | Number of iteration in a Chemotactic loop ($N_c$) | 5 |
| 4 | Number of reproduction ($N_{re}$) | 4 |
| 5 | Number of elimination and dispersal event ($N_{ed}$) | 1 |
| 6 | Probability with which the elimination and dispersal($P_{ed}$) | 0.25 |

## 7) Simulation Results and Observations:

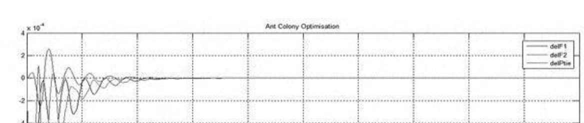
The simulation work is done for two area interconnected power system according to its block diagram and considering transfer function of each block simulation is done. At first conventional method is applied to get the Kp and Ki value and corresponding error value. Then PSO algorithm is applied to get the value of parameters of controller where ISE value is minimium.

The ACO algorithm is employed to tune the Ki parameter in the PI controller to minimize the ACE based on minimum ISE index.

To indicate the robustness of the mentioned controller simulations are done on time domain for step load change at various areas and with parameter variations. The responses with PI controller optimized by using objective function ISE is considered with 2% load change

A step load of 0.02 p.u in both areas as given and the corresponding frequency deviations as shown in figure 2, 3 and 5.

**Frequency deviation with ACO, PSO and BFOA techniques:**



### 8) Comparison of ACO, PSO and BFOA techniques:

The frequency deviation in area1, area2 and tie-line power are compared by ACO, PSO and BFO Algorithm technique

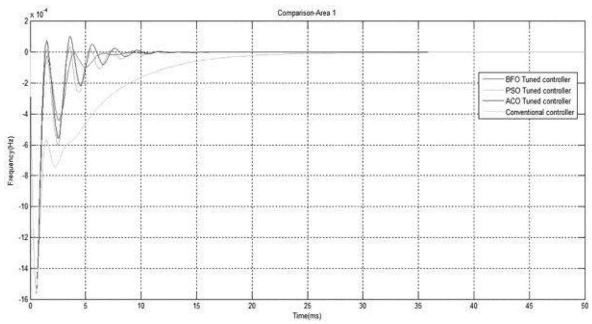



Figure 7 – Frequency deviation in area 1 only

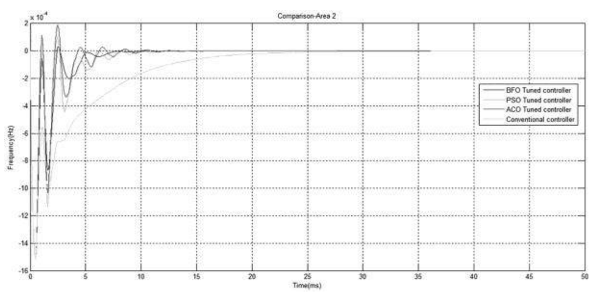



Figure 8 – Frequency deviation in area 2 only

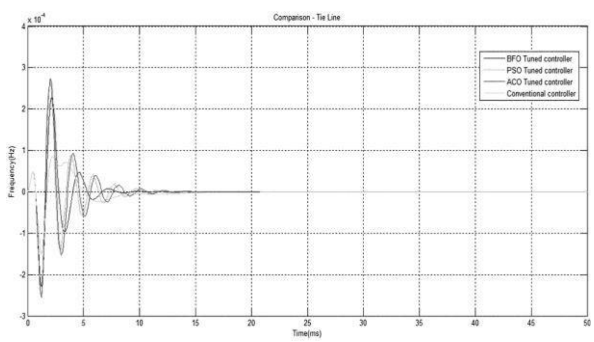



Figure 9 – Frequency deviation in Tie-line only

**Table 2: Performance Comparison of different tuning methods**

| Method | Area 1 | | Area 2 | | Peak Overshoot | | Settling Time (ms) | |
|---|---|---|---|---|---|---|---|---|
| | Kp | Ki | Kp | Ki | Area 1 | Area 2 | Area 1 | Area 2 |
| Z - N | 12 | 20 | 12 | 20 | 0.0016 | 0.0015 | 32 | 32 |
| ACO | 27 | 33.2 | 27 | 33.2 | 0.0016 | 0.0015 | 18 | 17 |
| PSO | 27 | 28.65 | 27 | 28.65 | 0.0016 | 0.0015 | 14 | 14 |
| BFO | 23 | 31.5 | 23 | 31.5 | 0.0016 | 0.0015 | 11 | 10 |

## Conclusion:

In this paper, Integral gain setting have been optimized by Ant Colony Optimization, Particle Swarm Optimization and Bacterial forging optimization technique. Thus the above optimization technique is used to tune the parameters of proportional plus integral controllers and the output is compared with the results from ACO, PSO and BFOA techniques. Thus BFOA technique provide better results than compared to PSO and ACO.

## Appendix

System Data:

Rating of each area = 1000 MW, Base power = 1000 MVA, $f^o$ = 50 Hz, $R_1$ = 0.05, $R_2$ = 0.0625, $R_3$ = 0.045, $R_4$ = 0.055 Hz / p.u.MW, $T_{g1}$ = 0.2 ms, $T_{g2}$ = 0.08 ms, $T_{gh1}$ = 0.3 ms, $T_{gh2}$ = 0.3 ms, $T_{t1}$ = 0.5 ms, $T_{t2}$ = 0.3 ms, $T_{w1}$ = 1 ms, $T_{w2}$ = 2 ms, $K_{p1}$ =1, $K_{p2}$ = 1 Hz/p.u.MW, $D_1$ = 0.6, $D_2$ = 0.9, $\beta_1$ = 0.0436, $\beta_2$ = 0.0439 p.u.MW / Hz, $2\pi T_{12}$ = 1 p.u.MW / Hz, a12 = -1, $\Delta P_{D1}$ = 0.02 p.u.MW

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