Assessment of Optimal PID Tuning Controllers for Load Frequency Control

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Abstract: - This paper presents two methods for designing the parameters of PID controller, the first is the Particle Swarm Optimization technique and the second is a Bacterial Foraging Optimization Algorithm. These two methods are used to search for optimal parameters of the controllers to minimize the performance index. A two area thermal system is considered for design and analysis. In each area LFC monitors the system frequency deviations and tie line power which gives the net change in area control error. If the ACE is made to zero, then both tie line power and frequency will be forced to zero. The superiority of the proposed approach has been demonstrated by comparing the results and is observed that it could be easily extended to other global optimization problems.

Key Words: - LFC (Load Frequency Control), ACE (Area Control Error), PID (Proportional-Integral-Derivative), PSO (Particle Swarm Optimization), BFOA (Bacterial Foraging Optimization Algorithm).

1. Introduction

Now a day's power system network consists of a number of utilities interconnected together and power is exchanged between utilities over the tie line by which they are interconnected. The electrical products are not only sensitive to the continuity of power supply but also on the quality of power supply such as voltage and frequency.

The main objective of load frequency control is to regulate the output powers of the plant so that the frequency of the interconnected power system and tie line powers are kept within prescribed limits. The various control strategies for LFC of power system have been proposed and investigated by many researchers [1-4].

The researches in the world are trying to propose better load frequency control system based on modern control theory [6], the fuzzy system theory [7], neural network [8, 9] and ANFIS approach [10]. The literature review for load frequency control has been proposed [5] in which various configurations of power system models, their control strategies, the various load frequency control issues have been discussed in conventional and distribution generation based power system. From this literature review it reveals that the heuristic techniques have still scope in better tuning of controller parameters for the improvement of system performance. Recently the researchers are concentrating on solving the complexity issues in power system using GA [11], TSA [12], and PSO and currently in BFOA.

For the last decades many control techniques are used for designing optimal parameters for PID controllers such as classical control approach [13], the optimal control approach [14], adaptive and self tuning approach [14]. By investigating with this approaches it has been proved that system performance not only depend on the intelligent computing techniques but also on the objective function and also on the controller parameters. In this paper the robust PID controllers have been used to improve the performance of load frequency control problem. The optimization technique such as PSO and BFO are used for tuning the PID parameters.

2. Two Area Interconnected Power System

The two area power system with a controller which is used for investigation is shown in Fig1.Due to nonlinearities in connecting load and governor dead bands the response of the system is also nonlinear. The main goal of load frequency control is to maintain zero steady state errors for frequency deviation and also better tracking of load demands in interconnected areas.

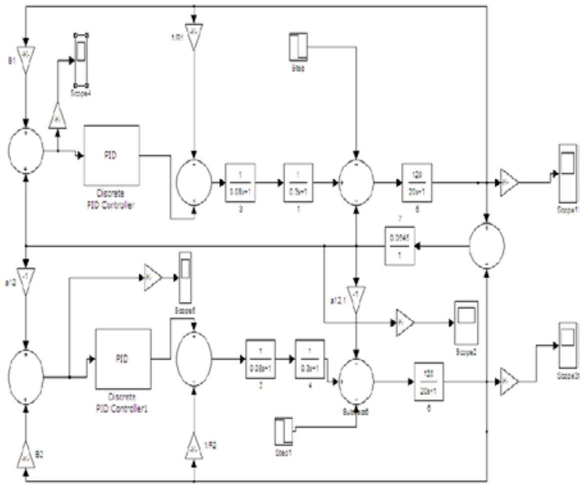

Fig 1: Two area interconnected power system with PID controller

The mathematical model for two area power system is

$$\dot{X} = AX + BU + rD \tag{1}$$

$$Y = CX \tag{2}$$

$$U = [u_1\ u_2]^T \tag{3}$$

$$D = [d_1\ d_2]^T \tag{4}$$

$$\Delta X = [\Delta F_1\ \ \Delta P_{T1}\ \ \Delta P_{G1}\ \ \Delta P_{C1}\ \ \Delta P_{tie}\ \ \Delta F_2\ \ \Delta P_{T2}\ \ \Delta P_{G2}\ \ \Delta P_{C2}]^T \tag{5}$$

$$Y = [y_1\ y_2]^T = [ACE_1\ \ ACE_2]^T \tag{6}$$

Where

F_i = system frequency (Hertz)

R_i = Regulation constant (Hertz/unit)

T_{Gi} = Speed governor time constant (s)

T_{Pi} = Power system time constant (s)

ΔP_{Di} = load demand change

ΔP_{Ci} = change in speed changer position

K_{Pi} = power system gain

ΔP_{tie} = change in tie line power

The PID controllers used for control in both areas are assumed to be same.

The structure of PID controller is

$$G\,(S) = K_p + \frac{K_i}{S} + K_d S \tag{7}$$

Where

K_p = Proportional gain

K_I = Integral gain

K_d = Derivative gain

The control equation for a PID controller is

$$U_i(s) = -(K_{pi}\ ACE_i + K_{Ii} \int ACE_i\, dt + K_{di} \frac{d\ ACE_i}{dt}) \tag{8}$$

3. Problem Formulation

A performance index can be defined as the integral of area control error multiplied by time of the frequency deviation of both areas and tie line power. The performance index J for the problem is

$$J = \int_0^\infty ACE_i * t\, dt \tag{9}$$

Minimize J subjected to

$$K_p^{min} \le K_p \le K_p^{max}$$

$$K_i^{min} \le K_i \le K_i^{max}$$

$$K_d^{min} \le K_d \le K_d^{max}$$

4. PSO Algorithm

The particle swarm optimization technique is used here for tuning PID parameters. The PSO algorithm can be used to solve the same kind of problems as Genetic Algorithm; it is also flexible and less susceptible to local optima [17]. The particle swarm optimization algorithm is population based stochastic optimization technique inspired by social behavior of patterns of organisms that live and interact within large groups. The PSO model consists of swarms of particles which correspond to individual in GA. [18]

The heuristic algorithm moves iteratively through n-dimensional search space for new solutions. The i^{th} particle is represented as

$$X_i = (x_{i1}, x_{i2}, x_{i3}, \ldots \ldots, x_{in}) \tag{10}$$

The position is given best fitness value (best previous solution) of any particle can be calculated as a measure of certain qualities. The ith particle is represented as

$$P_i = (p_{i1}, p_{i2}, p_{i3}, \dots \dots, p_{in}) \tag{11}$$

Similarly the velocity (position change) of each particle is

$$V_i = (v_{i1}, v_{i2}, v_{i3}, \dots \dots, v_{in}) \tag{12}$$

The particles are calculated using the following equation

$$V_i^{n+1} = W * V_i^n + C_1 * R_{i1}^n * (P_i^n - X_i^n) + C_2 * R_{i2}^n * \left(P_g^n - X_i^n\right) \tag{13}$$

$$X_i^{n+1} = X_i^n + x * V_i^{n+1} \tag{14}$$

Where

P_i = local best solution

P_g = global best solution

X_i = current position

n = number of birds

C_1, C_2 = PSO parameters

w = inertia weight parameter

4.1 Pseudo code for PSO

```
Procedure PSO
repeat
    for i = 1 to number of individuals do
        if G (x_i) > G (p_i) then
    G () evaluates goodness
            for d = 1 to dimensions do
                p_id = x_id   p_id is the best state found
                so far
            end for
        end if
        k = i
        for j = indexes of neighbors do
            if G (p_j) > G (p_k) then
                k = j        k is the index of
                best performer in neighborhood
            end if
        end for
    for d = 1 to number of dimension do
    v_id (t) = f (x_id (t-1), v_id (t-1), p_id, p_kd)
    update velocity
    v_id ϵ (-v_u + v_l)    update position
            x_id(t) = f (v_id(t), x_id(t-1))
        end for
    end for
until stopping criteria
end procedure
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5. Bacterial Foraging Optimization Algorithm

BFOA has been recently accepted as a global optimization algorithm for control and distributed optimization. BFOA proposed by K. M. Passino [19], is a newcomer to the family of nature inspired optimization algorithm. In BFOA E.coli bacteria works based on the law of evolution that the species which have better food searching ability survives and those which are poor are either reshaped or eliminated. The behavior of the bacteria can be clearly explained by four steps. [20]

5.1 Chemotaxis

The movement of bacteria can be defined by two ways depending upon their behavior as “swimming” (if it moves in predefined direction) and “tumbling” (if it moves in a new direction). In swimming the step length is predefined and in tumbling can be represented by random direction φ (j) multiplied by the step length of the bacteria C (i).

5.2 Swarming

If the bacterium finds the richest food location it should give signals to other bacteria so that they can converge on the desired location more rapidly. To obtain this a penalty factor based upon the distance of each bacteria from the fittest bacteria is added to the cost function and this penalty factor becomes zero when it reaches the optimum solution point.

5.3 Reproduction
The least healthy bacteria dies and the healthy bacteria asexually splits into two bacteria to make the swarm size constant

5.4 Elimination and Dispersal
An unknown event may occur which alter the smooth process of evolution and may even eliminate a set of bacteria. This event may place a new set of bacteria near the desired location, thus it helps in eliminating stagnation.

5.5 Pseudo code for BFOA
STEP 1: Initialize parameters P, S, Nc, Ns, Ned, Ped, Sr, (i = 1, 2,…….S)
Where

P = dimension of search space

S = number of bacteria

Nc = number of chemotaxis steps

Ns = maximum number of swim length

Ned = number of elimination and dispersal event

Ped = Elimination and dispersal probability

$\theta^{i(j,k,l)}$: Position of the i^{th} bacterium at j^{th} chemotaxis step, k^{th} reproductive step & l^{th} elimination step.

STEP 2: Elimination and dispersal loop: l = l + 1

STEP 3: Reproduction loop: k = k + 1

STEP 4: Chemotaxis loop j = j + 1

For i = 1, 2……S, take chemotaxis step for bacterium as follows:

Compute Fitness function J (i, j, k, l).Save this value in J_{last}, so that we can find better cost function.

Tumble: The direction vector del (i) is assigned a new value which is a random number lying between [-1, 1]

$$\theta(i+1,j,k) = \theta\,(i,j,k) + c(i)\frac{del(i)}{\sqrt{del^T}\,del(i)}$$

Move: Compute J (i, j+1, k, l)

Calculate the fitness function J (i, j+1, k, l)

Swim: (i) Let Sc = 0

(ii) If Sc < Ns

Let m = m + 1

If J (i, j, k, l) < J_{last} then $J_{last =}$ J (i, j+1, k, l) and

$$\theta(i+1,j,k) = \theta\,(i+1,j,k) + c(i)\frac{del(i)}{\sqrt{del^T}\,del(i)}$$

Else if Sc = Ns. This is the end of while statement

For next bacterium (i + 1) go to step (ii) if i ≠ S

STEP 5: If j < Nc, go to STEP 4 for the next chemotaxis process, since the life of bacteria is not over.

STEP 6: Reproduction: For current values of k, l Compute the overall fitness

$J_{health} = \sum_{j=1}^{Nc+1} J\,(i,j,k,l)$ For each bacteria and sort the fitness functions in ascending order of the cost function.

STEP7: The Sr bacteria with highest J_{health} value die and the remaning bacteria with best value splits, so the the population remains the same.

STEP 7: If k < Nre go to STEP 3.Increment the reproduction counter and new chemotaxis process starts.

STEP 9: Elimination- dispersion: Eliminate the bacterium with probability Ped.

STEP 10: If l < Ned then go to STEP 2; otherwise end.

6. Simulation Results and Discussion
The two interconnected areas were considered identical. Step size used for the two interconnected system are 1e-06. The upper and lower bound values for PID controller parameters are chosen as [-1, 1].

Table 1 gives the performance of the different controllers. Table 2 gives the optimal value of controller parameters obtained from the two methods.

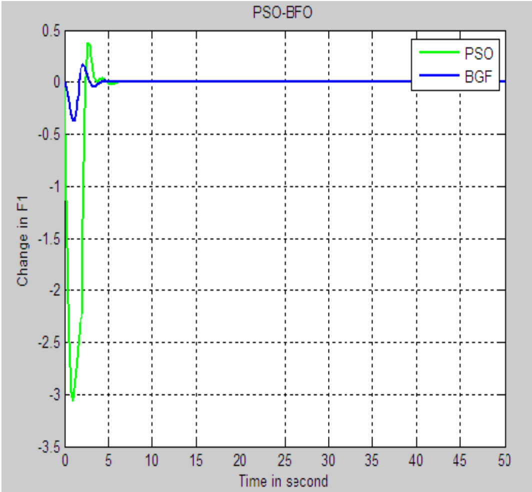

Fig 2: Change in frequency in area 1 for step load change

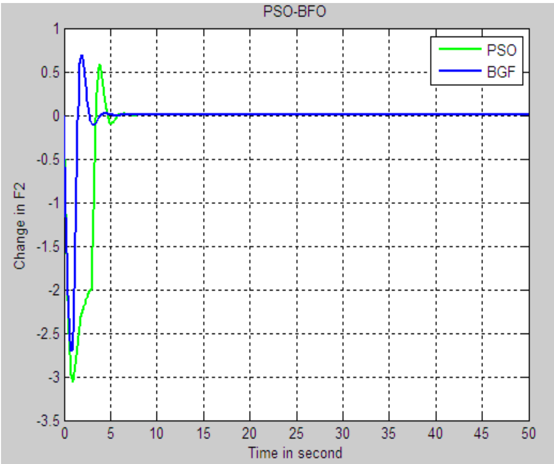

Fig 3: Change in frequency in area 2 for step load change

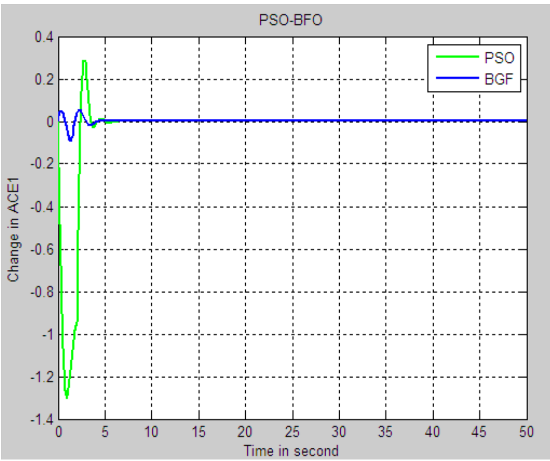

Fig 4: Change in ACE in area 1 for step load change

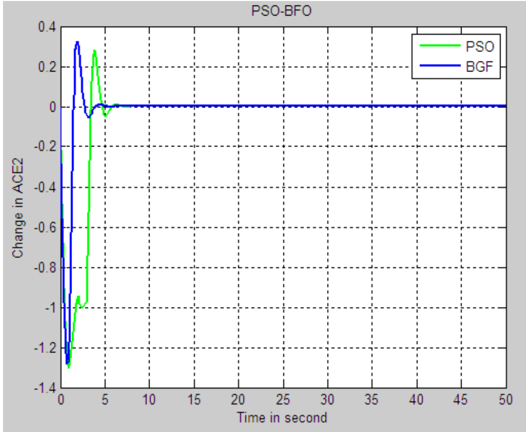

Fig 5: Change in ACE in area 2 for step load change

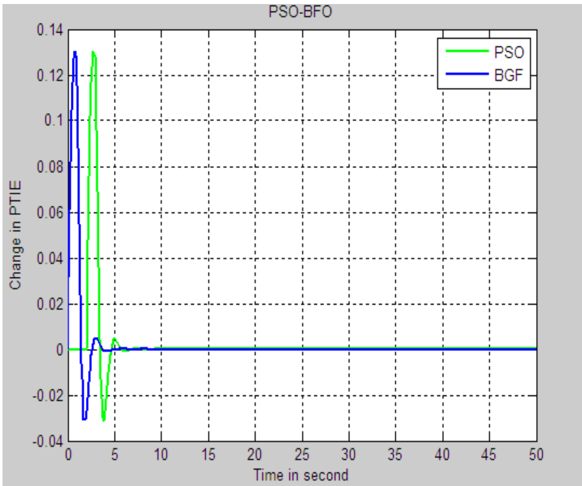

Fig 6: Change in Ptie for step load change

Table 1
Comparison table for the obtained results

PSO	Peak Overshoot (%)	Settling Time (s)	BFOA	Peak Overshoot (%)	Settling Time (s)
Change in F1	3.1	7	Change in F1	0.4	5
Change in F2	3.1	6	Change in F2	2.6	6
Change in ACE1	1.3	5	Change in ACE1	0.1	4
Change in ACE2	1.4	7	Change in ACE2	1.3	5
Change in Ptie	0.03	7	Change in Ptie	0.03	3

Hence from the results it can be concluded that the proposed BFOA is an optimal controller for tuning the PID controller compared with the Particle Swarm Optimization technique. The graph shows that the controller tuned with BFOA has produced less overshoot and faster settling time.

Table 2
Gain values for PSO and BFOA

Controller Parameters	PSO	BFOA
Kp	0.7900	0.7674
Ki	1.4252	0.1776
Kd	0.4652	0.1056

7. Conclusion

Hence from the graphical and empirical results, the proposed BFOA algorithm has simple architecture, lesser overshoot, better settling time and zero steady state error when compared with the heuristic algorithm. Since the settling time is significantly reduced it causes reduction in generating cost, thus providing economical benefits. The corrosion of the machinery can be prevented by lowering overshoot. The future work may be extended by improving the speed of convergence and learning using various hybrid optimization algorithms.

This global search optimization algorithm can find the optimal solution even when the population involved is small. It also eliminates premature convergence and enhances the search capability. It has the capability of implementing in real time environment, cooperative control, RF-ID network scheduling, antenna design, distributed computing etc.

The social foraging behavior of Escherichia coli bacteria is currently gaining popularity for its effectiveness in solving certain difficult real world optimization problems.

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