Design of Load Frequency Controller using Gorilla Troops Optimizer

[1]Dr.V.S.R.Pavan Kumar.Neeli, [2]M.Sunil Kumar, [3]M.Vijay Raghavendra, [4]K.Kotaiah Chowdary, [5]Dr.N.Sameera

[1,5]Associate Professor, [2, 3, 4] Assistant Professor

SIR C R Reddy College of Engineering, Eluru, Andhra Pradesh, INDIA

Abstract: This paper proposes a new metaheuristic algorithm inspired by gorilla troops social intelligence in nature, called Artificial Gorilla Troops Optimizer (GTO) has been used to determine the optimal values of the proportional-integral-deviation (PID) controller for the load frequency control. Single area power system has been designed as a model network for MATLAB-Simulink simulation. The comparison has been done between the PID controller tuned by Particle Swarmoptimization (PSO) and Bacteria Foraging optimization (BFO) technique. Based on time settling, transient and overshoot analysis, it can be concluded and profoundly proved that PID tuning by GTO technique is better than PSO and conventional BFO based PID controllers.

Index Terms - Gorilla Troops Optimizer, particle swarm optimization, bacterial foraging optimization, load frequency controller.

I. BACKGROUND OF THE STUDY

Power system networks consist of a number of utilities interconnected together and power is exchanged between the utilities over the tie-line [1]. Tie-line is the transmissionlines that connect an area to another neighbouring area. If there is any load perturbation takes place, it will affect all the area which is interconnected together. Thus, LFC helps in maintaining the scheduled system frequency and tie-line power interchange with the other areas within the prescribed limits [2]. A typical large-scale power system is composed of several areas of generating units. In order to enhance the fault tolerance of the entire power system, these generating units are connected via tie-lines. The usage of tie-line power imports a new error into the control problem, i.e., tie-line power exchange error. When a sudden active power load change occurs to an area, the area will obtain energy via tie-lines from other areas [3]. But eventually, the area that is subject to the load change should balance it without external support. Otherwise there would be economic conflicts between the areas. Each area requires a separate load frequency controller to regulate the tie-line power exchange error so that all the areas in an interconnected power system can set their setpoints differently. For this purposed, the LFC has two major assignments, which are to maintain the standard value of frequency and to keep the tie-line power exchange under schedule in the presences of any load changes [4]. In addition, the LFC has to be robust against unknown external disturbances and system model and parameter uncertainties. In industry, proportional-integral-Derivative (PID) controllers have been broadly used for decades as the load frequency controllers.

Many artificial intelligence (AI) based controllers have also been investigated by the various researchers like decentralized controllers such as sliding mode controller, artificial neural network (ANN) controller , fuzzy logic (FL) controller and neuro fuzzy controller [7]. Many optimization techniques have also been applied to tune the parameters of the various controllers such as Differential Evolution (DE), Genetic Algorithm [GA], Particle Swarm Optimization [PSO], Ant Colony Optimization [ACO], which are some of the heuristic techniques having immense capability of determining global optimum [8].

The main contributions of this paper are summarily given as follows:

1. Design the single area thermal power system in MATLAB/SIMULINK.

2. Gorilla Troops Optimizer (GTO), Particle Swarm Optimization (PSO) and Bacterial foraging optimization (BFO) has been investigated to determine the optimal values of PID controller for single area load frequency controller (LFC).

3.Then, all three optimization techniques has been compared in term of time settling, transient and overshoot to determine the best of Kp, Ki and Kd in PID controller.

II. TYPE STYLE AND FONTS

The objectives of the load frequency controller are to maintain reasonably uniform frequency, to divide the load between generators, and to control the tie-line interchange schedules. Basically, single area power system consists of a governor, a turbine and a generator with feedback of regulation constant. The system also includes step load change input to the generator [5]. This work mainly related with the controller unit of a single area power system. Simple block diagram of a single area power system with the controller is shown in Figure-1.

Figure 2.1: Single area power system network
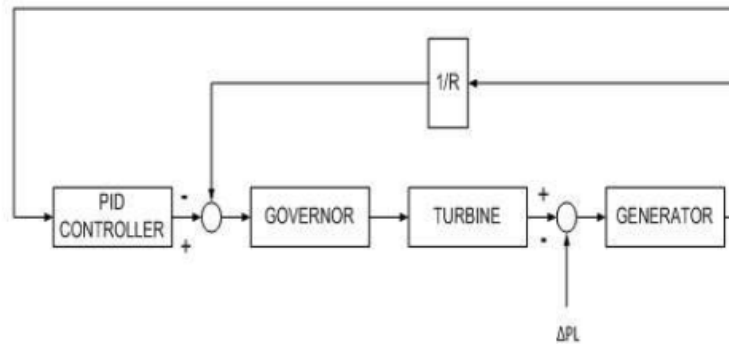
Ordinary Load Frequency Control generally is designed with proportional integral derivative (PID) controller. The parameter of this PID controller can be tuned using optimization technique which can cause the controller to provide designed control action which meets the requirement. PID controller consists of Proportional action, Integral action and Derivative action [9].

- The derivative term normally adds a finite zero to the open loop plant transfer function and can improve the transient response in most cases.
- The integral term adds a pole at origin resulting in increasing the system type and therefore reducing the steady-state error.
- PID controller's algorithm is mostly used in feedback loops, especially in the new industries because of robustness.

The PID controller has the following transfer function.

$$Gc(s) = K_p + \frac{K_i}{s} + K_d s^2$$

(2.1)

III. GORILLA TROOPS OPTIMIZER

Optimization denotes finding the best possible or desirable solution(s) to a problem commonly encountered in a wide range of fields. Optimization algorithms may show two types of behaviors when optimizing problems: deterministic and stochastic. Studies have demonstrated that most of the suggested metaheuristic algorithms have been inspired by animals' search and prey behavior in nature [10]. However, there is still no work that mimics gorilla troops lifestyle to design and develop a metaheuristic algorithm. This motivated our attempts to provide a mathematical model of gorillas' behavior and proposed Gorilla Troops Optimizer (GTO). In the GTO algorithm, five different operators are used for optimization operations (exploration and exploitation) simulated based on gorilla behaviors.

GTO generally follows the following several rules to search for a solution:
1. The GTO algorithm's optimization space contains three types of solutions, where the X is known as the gorillas' position vector, and the GX as the gorilla candidate position vectors created in each phase and operates should it performs better than the current solution. Finally, the silverback is the best solution found in each iteration.
2. Only one silverback in the entire population when considering the number of search agents selected for optimization operations.
3. Three types of X, GX, and silverback solutions simulate the gorillas' social life in nature accurately.
4. Gorillas can increase their power by finding better food sources or positioning in a fair and robust group. In GTO, solutions are created in each iteration known as GX in the GTO algorithm. If the solution found is new (GX), it replaces the current solution (X). Otherwise, it remains in memory (GX).
5. The tendency to a communal life among gorillas prevents them from living individually. Thus they look for food as a group and continue to live under a silverback leader, who makes all the group decisions. In our formulation phase, assuming that the worst solution in the population is the weakest member of the gorilla group, the gorillas attempt to turn away from the worst solution and get closer to the best solution (silverback), improving all the gorilla's positions.

The GTO algorithm's computational complexity depends on three main processes: initialization, fitness evaluation, and updating of vultures. Because there is an N gorilla, the computational complexity in the initialization process is equal to O (N).

On the other hand, the computational complexity in the update mechanism process is based on two phases of exploration and exploitation.

In each of the phases, an updating operation is performed on all the solutions in the optimization space, and the best solution is performed, which is equal to $O\ (T{\times}N) + O\ (T{\times}N{\times}D) \times 2$. Where T represents the maximum value of iterations, and D is the dimensions of the problems.

Therefore, the GTO algorithm's computational complexity is $O\ (N{\times}\ (1 + T + TD) \times 2)$.

The pseudocode of the GTO is described as follows:

% GTO setting

Inputs: The population size N and maximum number of iterations T and parameters β and p

Outputs: The location of Gorilla and its fitness value

% initialization

Initialize the random population X_i $(l = 1, 2, …, N)$

Calculate the fitness values of Gorilla

% Main Loop

while (stopping condition is not met) **do**

   Update the C using Equation $\Longrightarrow$ $C = F \times \left(1 - \dfrac{It}{MaxIt}\right),$

   Update the L using Equation $\Longrightarrow$ $L = C \times l.$

   % Exploration phase

for (each Gorilla (X_i)) **do**

   Update the location Gorilla using Equation

$$GX(t+1) = \begin{cases} (UB - LB) \times r_1 + LB, & rand < p, \\ (r_2 - C) \times X_r(t) + L \times H, & rand \geq 0.5, \\ X(t) - L \times (L \times (X(t) - GX_r(t)) + r_3 \times (X(t) - GX_r(t))), & rand < 0.5. \end{cases}$$

end for

% Create group

Calculate the fitness values of Gorilla

if GX is better than X, replace them

   Set $X_{silverback}$ as the location of *silverback* (best location)

   % Exploitation phase

   for (each Gorilla (X_i)) **do**

      if $(|C| \geq 1)$ **then**

      Update the location Gorilla using Equation $GX(t+1) = L \times M \times (X(t) - X_{silverback}) + X(t),$

      Else

      Update the location Gorilla using Equation $GX(i) = X_{silverback} - (X_{silverback} \times Q - X(t) \times Q) \times A,$

      End if

   end for

   % Create group

   Calculate the fitness values of Gorilla

   if New Solutions are better than previous solutions, replace them

   Set $X_{silverback}$ as the location of *silverback* (best location)

end while

Return $X_{BestGorilla}$, *bestFitness*

IV. OBJECTIVE FUNCTION

For any controller design which is employing with optimization methods, objective function is more generally specified depending on some of the performance criterias namely Integral of Time multiplied Absolute Error (ITAE), Integral of Absolute Error (IAE), Integral of Squared Error (ISE) & Integral of Time multiplied Squared Error (ITSE). It was clearly been shown in several studies that ISE based objective function offers and yields an improved system response as compared with other alternatives [6].

Therefore, ISE has been chosen as objective function in the current study which is written as:

$$J = \int_0^{t_{sim}} (\Delta F)^2 .dt$$

(4.1)

The objective function is to Minimize J, subjected to some constraints given below

$$K_{P1}^{min} \leq K_{P1} \leq K_{P1}^{max} ; \qquad K_I^{min} \leq K_I \leq K_I^{max} \qquad ; \qquad K_D^{min} \leq K_D \leq K_D^{max}$$

Where, ΔF is the deviation in frequency and t_{sim} is the simulation time.

V. MODELLING OF POWER SYSTEM

In this paper, simulink modeling of Load Frequency Control was created with PID controller. This simulink model is actually will interface with optimization technique's M-file to generate the best optimized value of Kp, Ki and Kd. This optimized parameter of PID will be replaced in PID controller's functional block parameter to generate frequency deviation graph. The block diagram of load frequency control that experimented in this paper is single are connected network. The single area connected network is the most simplified interconnected network of power system. With the optimized parameters based on GTO algorithm, the proposed PID controller of the LFC can achieve optimal properties. The block diagram of a single area power system with this controller is shown in Figure-2. The ordinary single area power system parameters consisting of the speed governor, turbine and generator are given in Table-1. Here the governor free operation is assumed and load demand $\Delta PL = 0.01$.
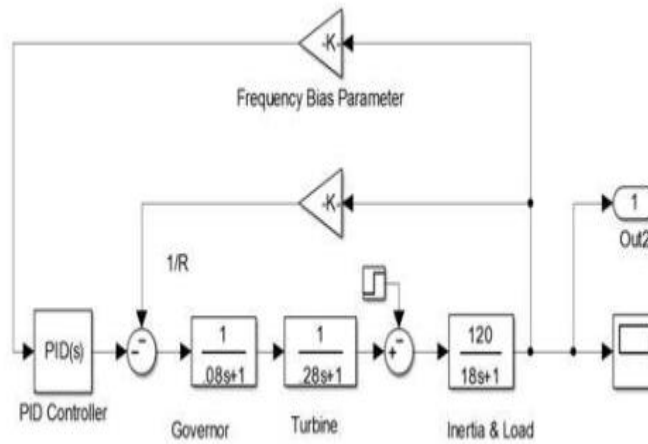
Figure .5.1: Block diagram of proposed power system

Table.5.1: Parameters of power system model

Description	Parameter	Value
Governor Gain	K_h	1
Governor Time Constant	T_g	0.08
Turbine Gain	K_t	1
Turbine Time Constant	T_t	0.28
Load Model Gain	K_y	120
Load Time constant	T_y	18

Governors are the units that are used in power systems to sense the frequency bias caused by the load change and cancel it by varying the inputs of the turbines. To bring the frequency back to the nominal value each generator with governor adjusts the turbine valve/gate (self regulation).Since electrical power is hard to store in large amounts, the balance has to be maintained between the generated power and the load demand. Once a load change occurs, the mechanical power sent from the turbine will no longer match the electrical power generated by the generator.

The power loads can be decomposed into resistive loads ΔPL which remain constant when the rotor speed is changing, and motor loads that change with load speed. If the mechanical power remains unchanged, the motor loads will compensate the load change at a rotor speed that is different from a scheduled value.

VI. SIMULATION RESULTS AND DISCUSSIONS

Generally, ordinary load frequency system is designed with Proportional-Integral-Derivative (PID) controllers. Since the "I" control parameter are always tuned, it is not capable in obtaining good dynamic performance for various load and system change scenario. However, for the comparison purpose, all the PID controllers which are tuned by different optimization techniques are taken in to account.

For the simulation of M-file of PSO, the m-file was run many times to generate the most precise and accurate PID parameter that giving zero steady state error for frequency deviation graph.

The M-file of the optimization technique of PID controller tuning by BFO was run in the MATLAB to generate the optimized value of PID gain which represent as Kp, Ki and Kd respectively as same method as PSO. For the simulation of M-file of PSO, the m-file was also run many times to generate the most precise and accurate PID parameter that giving zero steady state error for frequency deviation graph.

Similarly, M-file of GTO was run many times to generate the most precise and accurate PID parameter that giving zero steady state error for frequency deviation graph.

Figure-3 shows the comparison of graphs that has been generated for PID tuning by PSO, PID tuning by BFO and PID tuning by GTO. It was very obvious that PID controller tuned with GTO optimization technique gives short time settling compare with other PID controllers. This proved that the performance with GTO optimization technique is effective. Table-2 showed the optimal values of Kp, Ki and Kd that has been tuned by PSO, BFO and GTO algorithm and also ISE values of all techniques.

Overshoot is a distortion signal that may cause problem to the system if was continuously appear in the system without reducing the value. Overshoot have probability on causing the system malfunction or brings reliability problem that give huge problem to the power system and also increase the cost of maintenances.

By considering all these factors, which are time settling, transient and overshoot, it can be concluded and profoundly proved that PID tuning by GTO optimization technique is better than PSO and BFO optimization technique for the considered LFC problem.

Fig.6.1: Comparative frequency deviation response of various optimization techniques
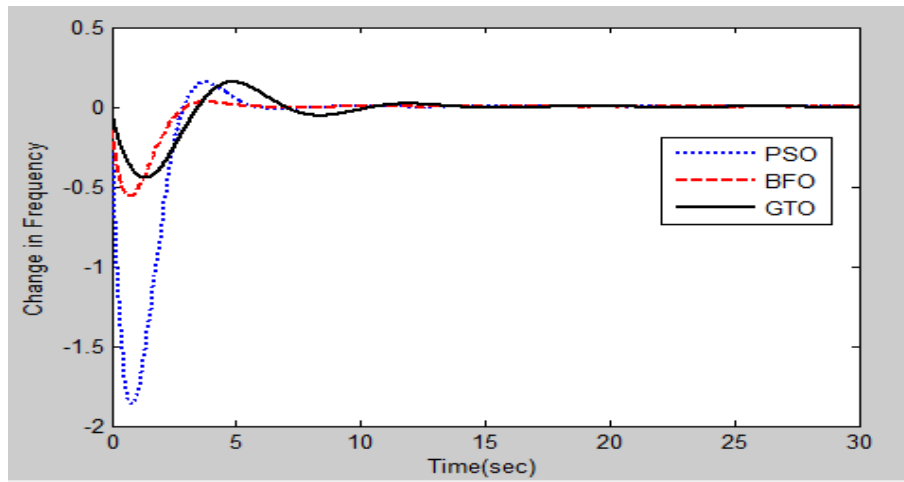

Table.6.1: Optimal Gain and ISE values

Parameters/ Method	K_P	K_I	K_D	ISE
PSO	0.0246	0.7586	0.1363	0.4222
BFO	1.7065	2.4623	0.9721	0.3757
GTO	1.2523	2.9157	2.9973	0.3364

VII. CONCLUSION

In this paper, Gorilla Troops Optimizer (GTO) based PID controller has been successfully proposed for Load Frequency Control problem. The proposed method was applied to a typical single-area of electric power system. It has been shown that the proposed control algorithm is effective and provides significant improvement in system performance. Therefore, the proposed GTO based PID controller is recommended to generate good quality and reliable electric energy. Whenever a disturbance is occurred, the time taken for the system to get back to normal operating condition is prominently done very quickly with GTO based PID controller.

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