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OPTIMAL LOAD FREQUENCY CONTROL IN SINGLE AREA POWER SYSTEM USING PID CONTROLLER BASED ON BACTERIAL FORAGING & PARTICLE SWARM OPTIMIZATION

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ABSTRACT
In this paper, meta-heuristic optimization based on Particle Swarm (PSO) and Bacterial foraging (BFO) 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 conventional PI controller and PID controller tuned by Particle Swarm and Bacteria Foraging optimization technique. Based on time settling, transient and overshoot analysis, it can be concluded and profoundly proved that PID tuning by BFO technique is better than PSO technique and conventional PI controller.

Keywords: particles swarm optimization, bacterial foraging optimization, load frequency controller.

INTRODUCTION
Power networks consist of a number of utilities interconnected together and power is exchanged between the utilities over the tie-line. Tie-line is the transmission lines 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. 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 set-points 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. In addition, the LFC has to be robust against unknown external disturbances and system model and parameter uncertainties. The high-order interconnected power system could also increase the complexity of the controller design of the LFC [22].

In industry, proportional-integral (PI) controllers have been broadly used for decades as the load frequency controllers. A PI controller design on a three-area interconnected power plant is presented in [21], where the controller parameters of the PI controller are tuned using trial-and-error approach. The LFC design based on an entire power system model is considered as centralized method. In [12] and [20], this centralized method is introduced with a simplified multiple-area power plant in order to implement such optimization techniques on the entire model. Many artificial intelligence (AI) based controllers have also been investigated by the various researchers like decentralized controllers such as sliding mode control [8],[13]'[14]&[19], artificial neural network (ANN) controller [6], fuzzy logic (FL) controller [5],[9]&[18], and neuro-fuzzy controller [16]. Many optimization techniques have also been applied to tune the parameters of the various controllers such as Differential Evolution (DE) [10],Genetic Algorithms[GAs],Practical Swarm Optimizations[PSO][23] Ant Colony Optimization[ACO][4], which are some of the heuristic techniques having immense capability of determining global optimum. In this paper, Particles 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). Then, both 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.

LOAD FREQUENCY CONTROL
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. 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.

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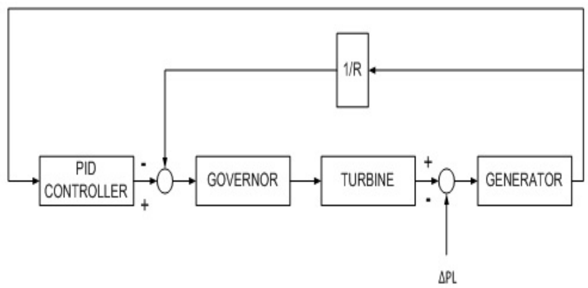

Figure-1. A single Area power system with PID controller.

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. It usually refers to Ziegler-Nichols PID tuning parameters. 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.

$$Gc(s) = K_p + \frac{K_i}{s} + K_d s^2 \tag{1}$$

PARTICLES SWARM OPTIMIZATION

Particle swarm optimization (PSO) is a population based stochastic optimization technique developed by Dr. Eberhart and Dr. Kennedy in 1995, inspired by social behaviour of bird flocking or fish schooling [23]. PSO shares many similarities with evolutionary computation techniques such as Genetic Algorithms (GA). The system is initialized with a population of random solutions and searches for optima by updating generations. However, unlike GA, PSO has no evolution operators such as crossover and mutation. In PSO, the potential solutions, called particles, fly through the problem space by following the current optimum particles. Figure-2 showed the flow diagram that illustrating the particle swarm optimization algorithm [23].

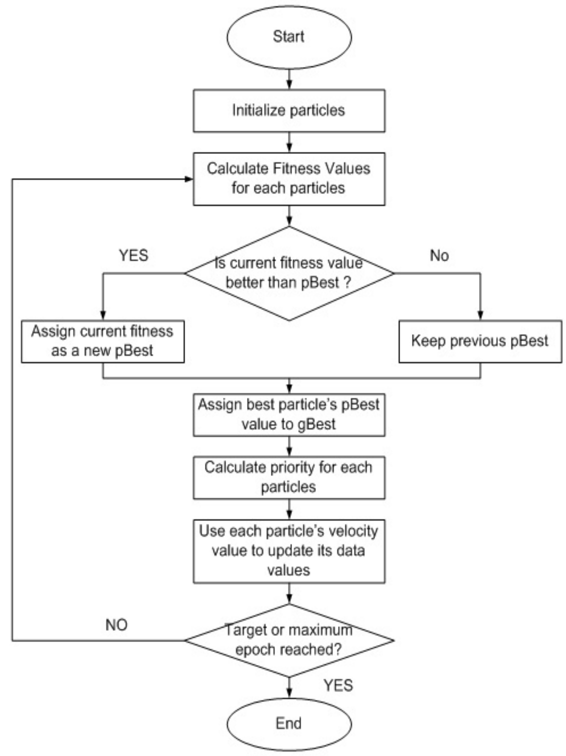

Figure-2. Flow diagram illustrating the particle swarm optimization algorithm.

Each particle keeps track of its coordinates in the problem space which are associated with the best solution (fitness) it has achieved so far. (The fitness value is also stored.) This value is called *pbest*. Another "best" value that is tracked by the particle swarm optimizer is the best value, obtained so far by any particle in the neighbours of the particle. This location is called *lbest*. When a particle takes all the population as its topological neighbours, the best value is a global best and is called *gbest*. The particle swarm optimization concept consists of, at each time step, changing the velocity of (accelerating) each particle toward its p*best* and *lbest* locations (local version of PSO). Acceleration is weighted by a random term, with separate random numbers being generated for acceleration toward *pbest* and *lbest* locations.

BACTERIAL FORAGING OPTIMIZATION

Bacterial Foraging Optimization (BFO) method was invented by Kevin M.Possino which mimics the natural selection which tends to eliminate the animals with poor foraging strategies and favours those having successful foraging strategies. The foraging strategy can divided into four process which are chemotaxis, swarming, reproduction and elimination and dispersal [3].

The general algorithm of BFO is shown in Figure-3 [11]&[17].

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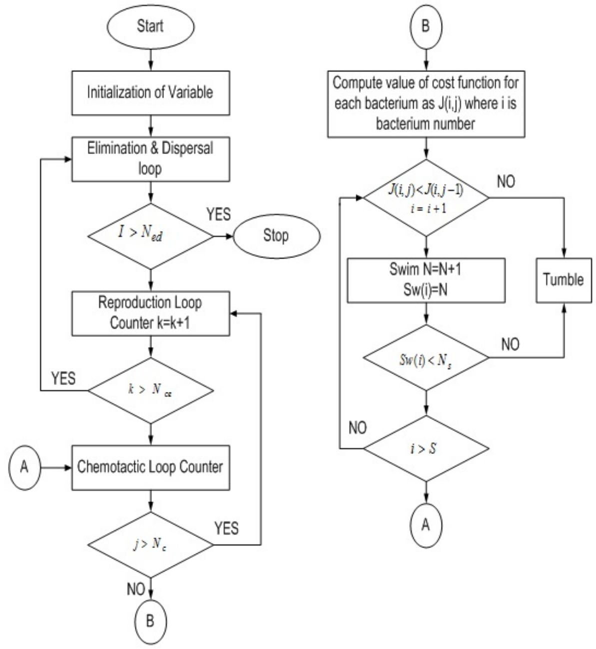

Figure-3. Flow diagram illustrating the bacterial foraging optimization algorithm.

(1) Chemotaxis

This process is the characteristic of movement of bacteria in searching food. This process can defined in two ways which are swimming and tumbling. When Bacteria move in a predefined direction it is called as swimming. Meanwhile the methods of tumbling is when the bacteria starts moving in an altogether different direction. Mathematically, tumble of any bacterium can be represented by a unit length of random direction multiplied with step length of that bacterium. Meanwhile for swimming, the random length is predefined. [15].

(2) Swarming

Bacteria practising swarm behaviour. This process starts when all the healthy bacteria attract other bacteria to together reach in the place where the food is rich which mathematically refer as solution point. A penalty function will be added to the original cost function to achieve the convergence of the bacteria. The penalty function is actually based on the relative distances of each bacterium from the fittest bacterium till that search duration. After the all bacteria merged into the solution point, this penalty function will become zero. The effect of swarming is to make the bacteria congregate into groups and moves as concentric patterns with high bacterial density.

(3) Reproduction

In this stage, the healthy or best set of bacteria will divide into two groups. The healthier bacteria will replaces the other half of the bacteria which will be eliminated because of their poorer foraging abilities. This makes the population of the bacteria always constant in the evolution process.

(4) Elimination & dispersal

In the evolution process, a sudden unforeseen event might occur which may drastically alter the smooth process of evolution and cause the elimination of the set of bacteria and/or disperse them to a new environment. This unknown event might place the newer set of bacteria near to the food location although it will not disturbing the usual chemotactic grow of the set of bacteria. When this method applied in optimization, it actually helps in reducing the behaviour of stagnation which often appears in some algorithm that practising parallel search.

The flow chart of PID tuning by BFO is shown in Figure-4. The best values of Kp, Ki and Kd can be generated using this algorithm.

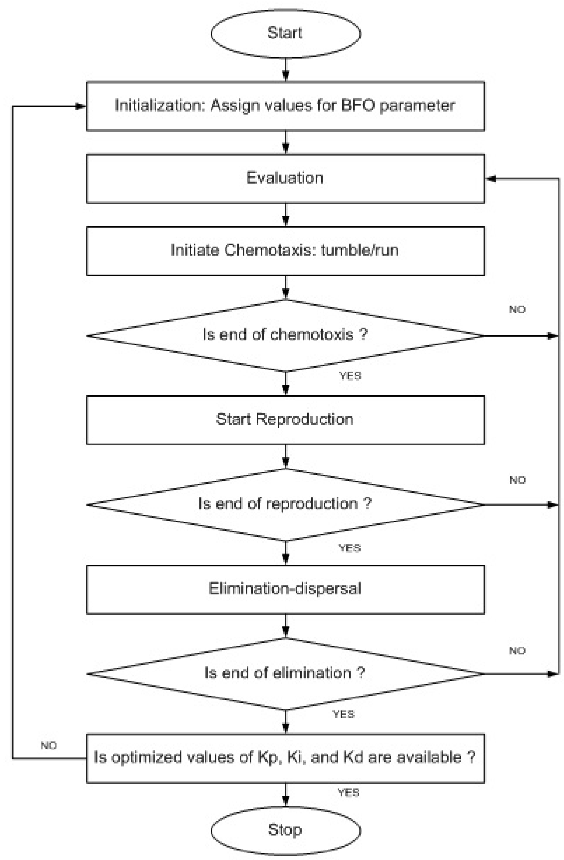

Figure-4. Flow chart of PID tuning by BFO.

POWER SYSTEM MODELLING

In this project, 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

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load frequency control that experimented in this project 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 BFO 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-5. 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 ΔPL = 0.01.

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. This error between the mechanical (ΔPm) and electrical powers (ΔPe) is integrated into the rotor speed deviation (Δωr), which can be turned into the frequency bias (Δf) by multiplying by 2π.

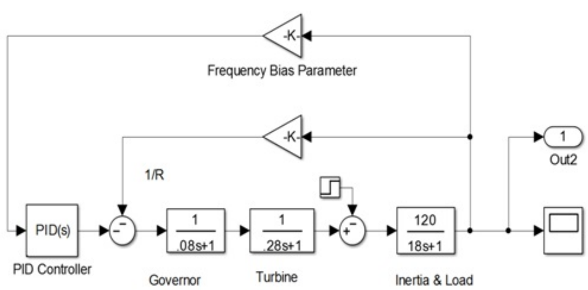

Figure-5. Simulink block diagram of load frequency control single area connected network.

Table-1. The parameter in LFC block diagram.

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

The relationship between the mechanical power ΔP_m and the electrical power ΔP_e is given by;

$$M \frac{d\Delta w}{dt} = \Delta P_m \tag{2}$$

Where Δw rotor speed deviation and M is inertia constant.

The power loads can be decomposed into resistive loads ΔP_L which remain constant when the rotor speed is changing, and motor loads that change with load speed [2]. 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. In general the expression of the electrical power which depends on the change on the frequency can be expressed by;

$$\Delta P_e = \Delta P_L + D\Delta w \tag{3}$$

Where ΔP_L is Non-frequency-sensitive load change, D is Load-damping constant and $D\Delta w$ is Frequency-sensitive load change. The block diagram form representation of (2) and (3) is shown in Figure-6.

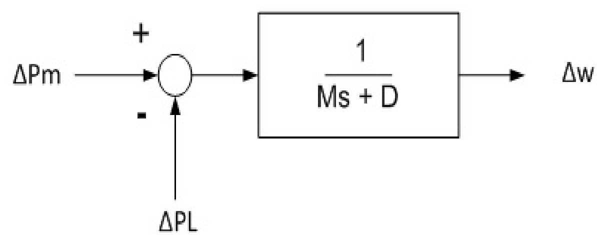

Figure-6. Block diagram representation of relationship between speed and power.

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). The schematics of such governor control system that used in this work are shown in Figure-7 [1].

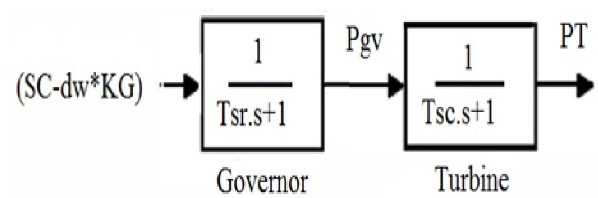

Figure-7. Block diagram of governor-turbine model.

The mathematical formulations of this model are given by;

$$\frac{dP_{gv}}{dt} = \frac{1}{T_{sr}}\left[SC - \left(KG^{*}dw\right) - P_{gv}\right] \tag{4}$$

$$\frac{dPT}{dt} = \frac{1}{T_{sc}}\left(P_{gv} - PT\right) \tag{5}$$

dw: Frequency deviation,
SC: Speed change,
KG: Speed governor gain,
T_{sr}: Governor time constant,
T_{sc}: Turbine time constant.

SIMULATION RESULTS

Generally, ordinary load frequency system is designed with Proportional-Integral (PI) 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, this conventional PI controller will be compared with the PID controller which is tuned by using optimization technique. The predefined parameters that widely used in conventional PI controller for load frequency control are shown in Table-2. The graph generated from the parameter in Table-2 is shown in Figure-8.

Table-2. Gain parameter for conventional PI controller [7].

Kp	Ki	Kd	Time Settling, Ts (sec)
0.45	0.65	-	13

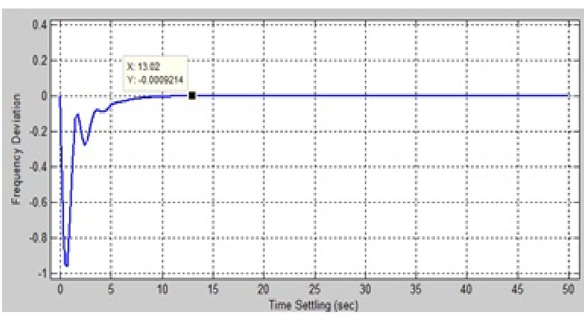

Figure-8. Frequency deviation graph for conventional PI controller.

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 parameter that varied in the PSO m-file was showed in the Table-3.

Table-3. Parameter table of M-file that varied for PID tuning by PSO.

Variables	Parameter
n	80
Bird Step	10
Dimension	3
c2	0.01
c1	0.04
w	0.2
Initial position	4*(rand(dim,n))

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. The parameter that varied in the BFO m-file was showed in the Table-4.

Table-4. Parameter table of M-file that varied for PID tuning by BFO.

Variables	Parameter
P	3
S	10
Nc	5
Ns	3
Nre	4
Ned	2
Sr	s/2
Ped	0.25
Initial Position	P(1;1,1,1)=.05*rand(s,1) P(1;1,1,1)=.05*rand(s,1) P(3;1,1,1)= .5*rand(s,1)

Figure-9 shows the comparison of graphs that has been generated for Conventional PI Controller, PID tuning by PSO and PID tuning by BFO. It was very obvious that PID controller tuned with optimization technique gives short time settling compare with conventional PI controller. This proved that the performance with optimization technique is effective. Table-5 showed the optimal values of Kp, Ki and Kd that has been tuned by PSO and BFO algorithm.

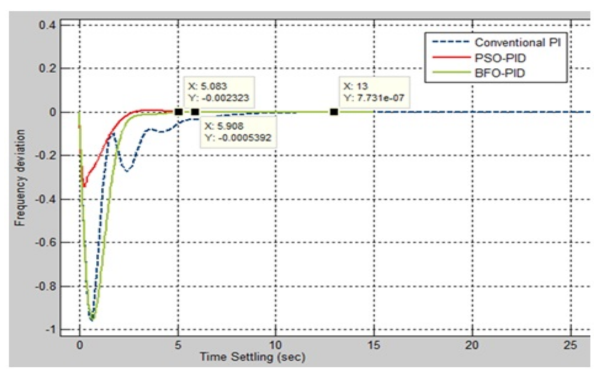

Figure-9. Compared frequency deviation graph for LFC in power system by various techniques.

Table-5. Optimal gain for PID controller.

Parameter / Method	K_p	K_i	K_d
PSO	1.7065	2.4623	0.9721
BFO	0.0246	0.7585	0.1363

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In terms of comparing both optimization techniques, PSO and BFO, in the Table-6 vividly showed that the smaller time settling for PID tuned by BFO was successfully achieved. In obtaining zero steady state error, all the techniques performed was almost reach to the zero which can be assumed as zero since the value of deviation are very small.

By comparing the transient of the graph, BFO and PI Controller have very high transient. However, the transient for BFO only appear for very short time compared with PI Controller. Although the transient of PSO is small but the appearance of transient in terms of time is similar to BFO.

Table-6. Summarize data of optimization technique for LFC.

Optimization technique	Time settling, Ts (sec)	Frequency Deviation, Δf (p.u.)
Conventional PI Controller	13.00	7.731e-07
PID tuning by PSO	5.91	-0.00054
PID tuning by BFO	5.08	-0.002323

If comparing the overshoot, both Conventional PI Controller and BFO do not have any overshoot for this system. However, for PSO it seems have slight overshoot on its graph. The overshoot is 7.6 x 10^{-3} p.u. deviated from the zero steady state. Overshoot refers to the transitory values of any parameter that exceeds its final (steady state) value during its transition from one value to another.

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.

Having the overshoot or transient in a system actually will cause stability problem. For example, conventional PI control although have no overshoot but there is transient effect that can cause the system not stable. Meanwhile, for PID tuning by PSO, the slight overshoot also can cause stability problem but not as worse as conventional PI Controller. But for BFO, it has acceptable stability and giving fast response to time settling.

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

CONCLUSIONS

In this paper, bacterial foraging algorithm (BFO) 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 PID-BFO controller is recommended to generate good quality and reliable electric energy.

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