

**Optimisation of PID controller for load  
frequency control in two-area power  
system using evolutionary particle  
swarm optimisation**

The main objectives of load frequency control (LFC) are to regulate the electrical power supply in two-area power system and change the system frequency and tie-line load. The performance of LFC has to be tuned properly so that its performance can be optimised. However, most of the tuning processes are performed through trial and error until the best performance is achieved. Therefore, to overcome this situation, in this work, particle swarm optimization (PSO) and evolutionary particle swarm optimization (EPSO) algorithms were employed in a LFC of two-area power system to optimise the performance of the PID controller. The purpose of using PID controller is to improve the performance of the LFC. Comparison of the performance using PSO and EPSO was made to identify which algorithm is better in controlling the performance of the LFC. It was found that using EPSO, the performance of the LFC is better in terms of settling time and rise time than using PSO. Hence, by implementing an optimisation method, the performance of the LFC can be optimised through optimising the PID controller parameters.

**Keywords:** PID controller; power system; swarm optimisation; load frequency control.

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## 1. Introduction

Dynamic behaviour of the power system causes many industrial loads to experience noise and in particular changes in the operating points [1]. The most important aspect in the power systems is to maintain the frequency and power change in order to supply reliable electric power [2]. To improve the stability of the power system network, it is needed to design load frequency control (LFC) system, which controls the power generation and active power. The LFC goal is to maintain a stable system frequency that has a zero steady-state error and to provide load sharing between two-area power systems in different interconnected systems. In addition, the power system must meet the requirements of the proposed method. Power system is divided into control areas related to the tie-line. All generators should form a coherent group within each control area [3].

Many studies have been conducted in the past about load frequency control. Since the past, several control strategies have been proposed by conventional linear control theory [4]. The controller may not be accurate in certain operating conditions. This is probably due to the complexity of power systems, such as the characteristics of the nonlinear load and change in operation. Different techniques such as Fuzzy Logic, Genetic Algorithms (GA) and Particle Swarm Optimization (PSO) algorithm have been used to determine the parameters of the PID controller according to the dynamical system [5].

Generally, LFC systems are designed with a proportional-integral (PI) controller [3] and proportional-integral-derivative (PID) controller. The PID controller is the most popular controllers used in the industry because of their remarkable effectiveness, simplicity of

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implementation and extensive usability. However, manual tuning controller takes a long time and generally leads to poor performance [6]. PID controller is a robust controller and has been used for a long time since the past.

Load frequency control is one of the most important aspects in power system operation and becomes more pronounced recently by increasing the size, structure and complexity of change in the recovery, especially in two-area power system. Normally, for large-scale power systems of interconnected subsystems or multi area power control, the connection between control areas is done by using a tie-line. Each region has its own generator or it is responsible for interchange power with neighbouring areas. To ensure the quality of supply, load frequency controller is required to maintain the system frequency at nominal value [7].

PID controller is one of the technologies which been used by 90% of automatic controllers in industrial control systems. PID controller was first placed in the market in 1939 and has been widely used in process control to date. The basic function of this controller is to implement an algorithm based control input and thus to maintain production at a level so that there is no difference between the reference and output [8].

PID controller improves the transient response of the system by reducing the overshoot and shortens the time to solve the stabilising system [9]. Tuning a PID controller requires setting the proportional, integral and derivative values to obtain the best control for specific processes and control gains to meet performance specifications, such as margin stability, transient response and bandwidth. Although trial and error can be used, PID controller may not achieve its optimum operation [10]. Using algorithms such as PSO and EPSO are the best way to determine the optimum parameters of PID controller. Minimizing the integral of time-weighted absolute error (ITAE) is commonly referred to as a good performance index in designing PID a controller [11]. The search of controller parameters can be obtained for particular types of load or set point changes and as this criterion is based on calculation error.

In this work, PID parameters are tuned for load frequency control in two-area power system by using PSO technique. The selection of the optimum PID controller parameters is obtained by optimisation technique, which is PSO and evolutionary (EPSO) algorithms. Comparison between these algorithms was made by computing the settling time and rise time.

## 2. Notation

The notation used throughout the paper is stated below.

### *Indexes:*

ACEA	Area control error
EPSO	Evolutionary Particle Swarm Optimization
GA	Genetic Algorithm
ITAE	integral of time-weighted absolute error
LFC	Load Frequency Control
PID	Proportional, Integral and Derivative
PSO	Particle Swarm Optimization

### *Constants:*

$K_p$	Proportional gain for PID controller
$K_i$	Integral gain for PID controller
$K_d$	Derivative gain for PID controller

### 3. Modelling of PID controller for load frequency controller (LFC)

#### 3.1. Load frequency control model

A load frequency control for two-area power system with PID controller that has been modelled in this work is shown in Figure 1. The model is used to find the optimum parameter values of PID controller for LFC by using PSO and evolutionary (EPSO) algorithms. The values to be optimised are  $K_p$ ,  $K_i$  and  $K_d$  and the objective function is to minimise the integral of time-weighted absolute error.

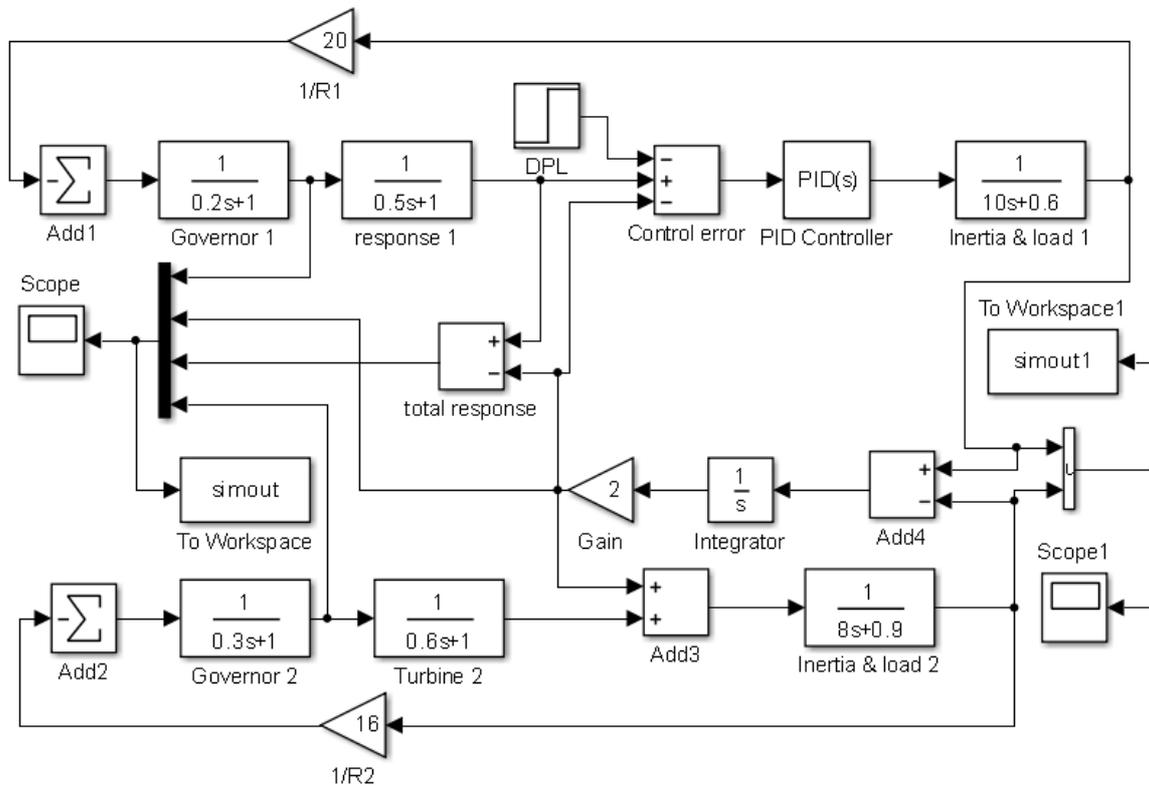


Figure 1: Simulation model of LFC for two-area power system

#### 3.2. Particle Swarm Optimization (PSO)

Particle swarm optimization (PSO) is a population (swarm) based stochastic optimisation algorithm, which is first introduced by Kennedy and Eberhart in 1995 [12, 13]. This method is motivated by the observation of social interaction and animal behaviours such as fish schooling and bird flocking. It mimics the way they find food by the cooperation and competition among the entire population [14]. PSO is a population based optimization tool. The system is initialized with a population of random solutions and searches for optima by updating generations. All the particles have fitness values, which are evaluated by the fitness function to be optimized and have velocities, which direct the flying of the particles. The particles are “flown” through the problem space by following the current optimum particles [15].

The function of PSO begins with the position of  $i^{\text{th}}$  particle of the swarm  $x_i$  and the velocity of this particle  $v_i$  at  $(t+1)^{\text{th}}$  iteration are defined [16]. All particles fly through a multidimensional search space, where each particle adjusts its position according to its own experience and neighbouring countries. Let the position vector of a particle shows multidimensional search space at time step, the position of each updated particles in the search space is given as

$$x_i^{t+1} = x_i^t + v_i^{t+1} \quad \text{with } x_i^0 \sim U(x_{\min}, x_{\max}) \quad (1)$$

where  $v_i^t$  is the velocity vector of the particle that drives the optimization process and reflects both own experience knowledge and the social experience knowledge from all particles, and  $U(x_{\min}, x_{\max})$  is the uniform distribution where  $x_{\min}$  and  $x_{\max}$  are its minimum and maximum values respectively.

Thus, in PSO, all particles are randomly initiated and evaluated for fitness count along with the best position (local best value of every particles) and global best position (best value in the entire swarm). After that, the loop begins to find the optimal solution. In the loop, the first particle velocity is updated by global and local bests and then the position of each particle is updated by the current velocity. The loop ends with stopping criteria after finding the best  $gbest$  value [17]. The best value is the solution for  $K_p$ ,  $K_i$  and  $K_d$ .

The global best (or  $gbest$ ) is a method where the position of each particle is influenced by the best-fit particle in the entire swarm. The personal best position will choose the position in search space where particle with the smallest value, as determined by the objective function. In addition, the position yielding the lowest value amongst all personal best is called the global best position [18]. Therefore, it is important to note that the personal best is the best position that the individual particle has visited since the first time step. On the other hand, the global best position is the best position discovered by any of the particles in the entire swarm.

For  $gbest$ , the velocity of the particle is calculated by

$$v_{iD}^{t+1} = v_{iD}^t + c_1 r_1 D^t [P_{besti}^t - x_{iD}^t] + c_2 r_2 D^t [G_{best} - x_{iD}^t] \quad (2)$$

where  $i = 1, 2, \dots, n$ ,  $n$  is the size of the swarm,  $D$  is dimension of the problem space, which is  $K_p$ ,  $K_i$  and  $K_d$ ,  $c_1$  and  $c_2$  are two positive constants,  $r_1$  and  $r_2$  are random numbers between 0 and 1,  $t$  determines the iteration number,  $v_{iD}^t$  is the velocity vector of particle  $i$  in dimension  $D$  at time  $t$ ,  $x_{iD}^t$  is the position vector of particle  $i$  in dimension  $D$  at time  $t$ ,  $P_{besti}^t$  is the personal best position of particle  $i$  in dimension  $D$  found from initialization through time  $t$  and  $G_{best}$  is the global best position of particle  $i$  in dimension  $D$  found from initialization through time  $t$ .

In PSO, the particles evolve the search space driven by three factors: inertia, memory and cooperation. Inertia implies particle store moving in the direction it had previously been moved. Memory factors affect the particle to remember the best the position of the search space that it has visited. Cooperation factor encourages particles to approach the best point in the space discovered by all particles. Each particle is the candidate for optimization

solutions problems, has its own position and velocity described as  $x$  and  $v$ . In brief, the algorithm of PSO is explained as follows:

1. Initialize a population of particles with random positions,  $x$  and velocities,  $v$  on  $D$  dimension to find the value of  $K_p$ ,  $K_i$  and  $K_d$ .
2. Evaluate desired optimisation fitness function in  $D$  variables for each particle.
3. Compare particle's fitness evaluation with its best previous position. If the current value is better, set the best previous position equals to the current value and local best position equals to the current location  $x_i$  in  $D$ -dimensional space.
4. Identify the particle in the neighbourhood with the best fitness so far and assign its index to the variable  $g$ .
5. Update velocity,  $v$  and position,  $x$  of the particle using equations (1) and (2).
6. Loop to step 2 until a criterion is met or end of iterations.

### 3.3. Evolutionary Particle Swarm Optimization (EPSO)

EPSO is a method based on a hybrid of two established optimization techniques, combining evolutionary computing and particle swarm optimization. EPSO operations are also called as particle movement because it seems to be more effective than recombination in generating solutions that are close to optimum. This model has a diversity to solve the objective function and easily completed with EPSO algorithm compared to classical PSO algorithm. EPSO starts like PSO, with a population of particles, generated randomly in the search space. Variables in the formulation of EPSO are divided according to the vocabulary used in Evolution Strategy society, consisting of parameter object (variable  $X$ ) and strategic parameters (weight  $w$ ). At a given iteration, consider a set of solutions or alternatives that is called particles. A particle is a set of object and strategic parameters  $[X, w]$ . The particle movement rule for EPSO is as follows, given a particle  $X_i$ :

- 1) Replication: Each particle is replicated  $r$  times (usually  $r$  is considered 2)
- 2) Mutation: The weights of the replicated particles are mutated according to

$$w_{ik}^* = w_{ik} + \tau N(0,1) \tag{3}$$

where  $\tau$  is a learning parameter (either fixed or treated as strategic parameters and therefore subject to mutation) and  $N(0, 1)$  is a random variable with Gaussian distribution of 0 mean and 1 variance.

- 3) Reproduction: Each particle generates an offspring, a new particle according to the movement rule [19], similar to the equations of conventional PSO.

The replicated particles make use of the mutated weights. The offspring is held separately for the original particles and the mutated ones. The value of  $g_{best}$  is also mutated using a so-called learning parameter ( $\tau'$ ). The velocity is calculated by

$$v_i^{k+1} = w_{i0}^* v_i^k + w_{i1}^* [P_{best} - x_i^k] + w_{i2}^* [g_{best}^* - x_i^k] \tag{4}$$

$$g_{best}^* = g_{best} + \tau' N(0,1) \tag{5}$$

where  $\tau$  is the learning parameter (either fixed or treated also as strategic parameters and therefore also subject to mutation),  $p_{best}$  is the best point found by particle  $i$  in its past life up to the current generation,  $g_{best}$  is the best overall point found by the swarm of particles in their past life up to the current generation,  $x_i^k$  is the location of particle  $i$  at generation  $k$ ,  $v_i^k$  is the velocity of particle  $i$  at generation  $k$ ,  $w_{i1}$  is the weight conditioning the inertia term, and  $w_{i2}$  is the weight conditioning the memory term.

4) Evaluation: Each particle is evaluated according to their current position.

5) Selection: The best particles are selected by stochastic tournament or other selection procedure, to form a new generation.

### 3.4. Objective function

The objective of PSO and EPSO is to obtain the parameters ( $K_p$ ,  $K_i$  and  $K_d$ ) by minimisation of  $F(x_i)$  using optimum value of  $x_i$  ( $i = 1, 2, \dots, N$ ). The objective function is defined as  $F(x_i)$ . The algorithm starts with  $N$  particles. Each particle represents a candidate solution to the problem, which has a current position of  $x_i$  ( $i = 1, 2, \dots, N$ ) and a current velocity  $v_i$  in the search space. The value of each particle is determined by the fitness function  $F(x_i)$ . The objective function is based on the Integral of Time and Absolute Error (ITAE) expressed by [20]

$$f = \sum_{j=1}^N \sum_{i=1}^N \left( \int_0^{\infty} t |\Delta f_i^j| dt \right) \quad (6)$$

where  $N$  is the number of areas in the power system and  $\Delta f$  is the frequency deviation in area  $i$  for step load changes in area  $j$ .

## 4. Case studies

To find the optimum parameters of the PID controller, PSO and EPSO methods were employed. In these methods, the position and velocity of the particles were updated to minimise the objective function, which is the ITAE function. With the optimized parameters based on the PSO algorithm, the performance of the LFC can achieve the optimum level.

### 4.1. Selection of PSO and EPSO parameters

Before employing the PSO algorithms, certain parameters need to be assigned first. The selection of this parameter is needed to find the optimised parameter values ( $K_p$ ,  $K_i$ ,  $K_d$ ). The maximum velocity affects the ability of the escape from the local optimization and global best optimisation. These are the parameters used for searching the global best and the optimum parameters of the PID controller. In this study, for each algorithm, the same iteration number, same size of the swarm and also other parameters were used in both algorithms. Table 1 shows the parameter values for PSO and EPSO in the two-area power system.

Table 1: Parameter values for PSO and EPSO in the two-area power system

Parameters	Value for PSO	Value for EPSO
Population size	50	50
Number of iterations	20	20
Velocity constant 1, $c_1$	1.2	1.2
Velocity constant 2, $c_2$	0.12	0.12
Weight, $w$	0.9	0.9
Upper bound, $U_b$	[1.5 0.5 1.0]	[1.5 0.5 1.0]
Lower bound, $L_b$	[0.01 0.01 0.01]	[0.01 0.01 0.01]
Learning parameter, $\tau$	-	0.3
Mutated learning parameter, $\tau'$	-	0.3
Mutated weight 1, $w_1$	-	0.9
Mutated weight 2, $w_2$	-	0.9

4.2. Test results

Table 2 shows the optimum parameter values of  $K_p$ ,  $K_i$  and  $K_d$  for PID controller using PSO and EPSO algorithms and without optimisation. Figure 2 shows the frequency deviation of LFC using PSO and EPSO algorithms and without optimisation while Figures 3 and 4 show the power deviation by using the optimised parameter values of the PID controller. Figure 5 shows the convergence curve of PSO and EPSO. The results from Figure 2 can also be seen in Table 2. From Table 2, the frequency deviation from EPSO is better than PSO, especially the settling time and rise time. EPSO also converges faster than PSO. This is due to in EPSO, replication, mutation and reproduction speed up the search towards global minimum [21-28]. Both optimisation methods yield a better performance of the LFC than without optimisation method.

Table 2: Optimum value of  $K_p$ ,  $K_i$  and  $K_d$  for PID controller with PSO and EPSO algorithms and without optimisation

Algorithm	$K_p$	$K_i$	$K_d$
Without optimisation	1.00	0.25	0.30
PSO	1.2995	0.01	0.1151
EPSO	1.4694	0.01	0.3409

Table 3: LFC performance for frequency deviation using PSO and EPSO algorithms and without optimisation

Algorithm	Settling time (s)	Rise time (s)	Convergence iteration	Lowest ITAE
Without optimisation	18.8	0.192	-	2.5147
PSO	17.3	0.2005	12	2.5007
EPSO	17.2	0.1700	11	2.4423

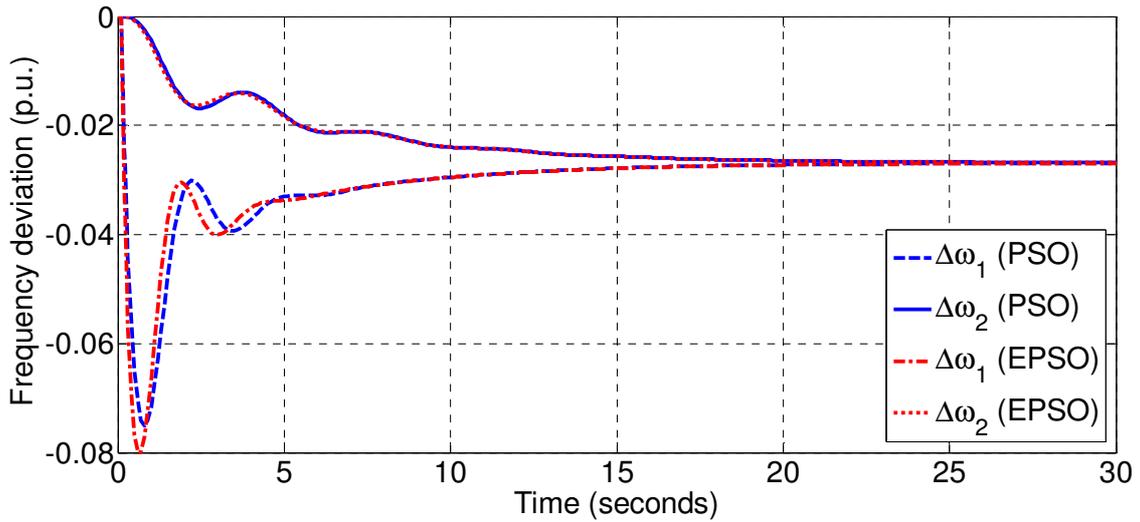


Figure 2: Frequency deviation,  $\Delta\omega_1$  and  $\Delta\omega_2$  using PSO and EPSO algorithms

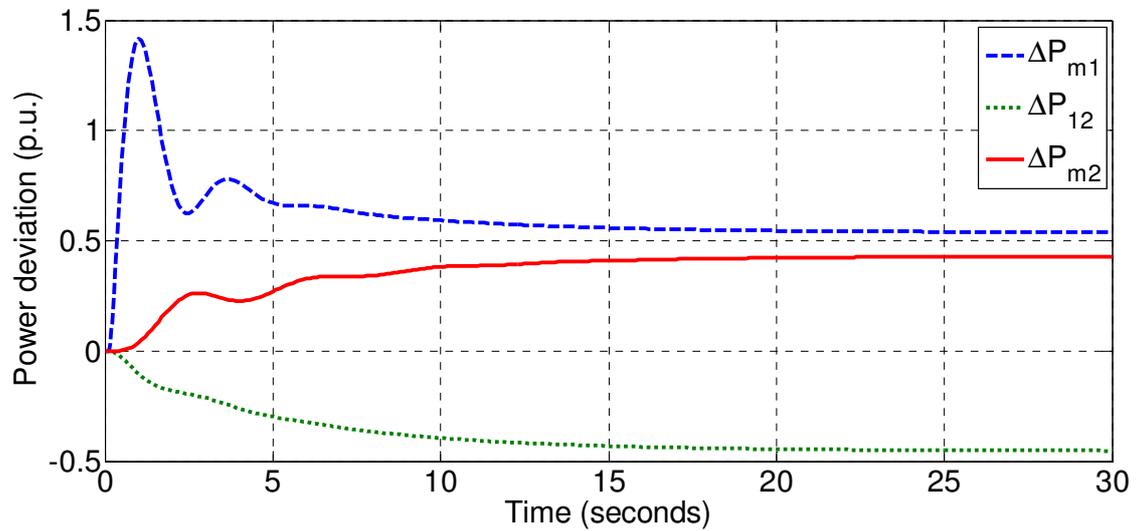


Figure 3: Power deviation using PSO algorithm

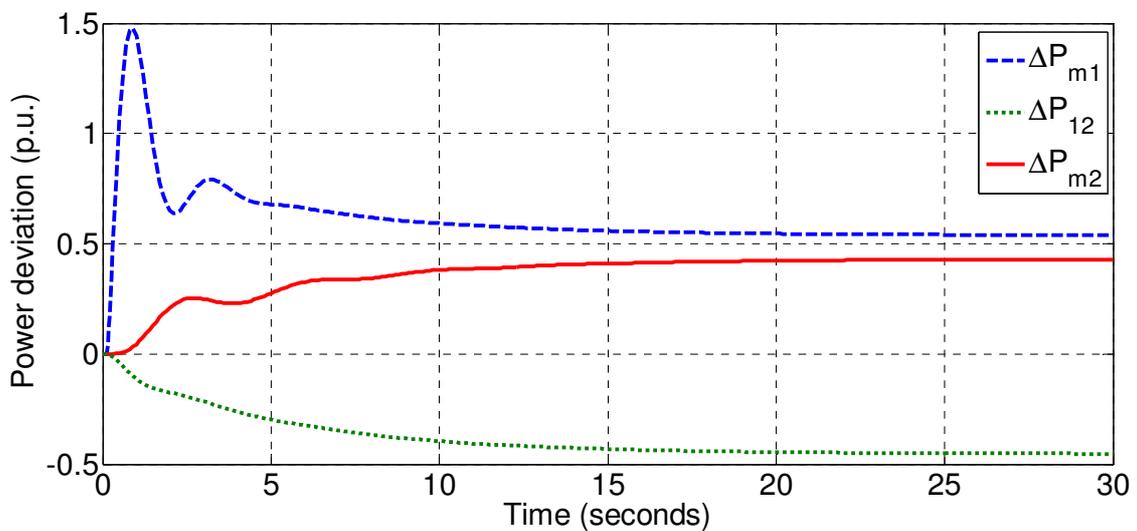


Figure 4: Power deviation using EPSO algorithm

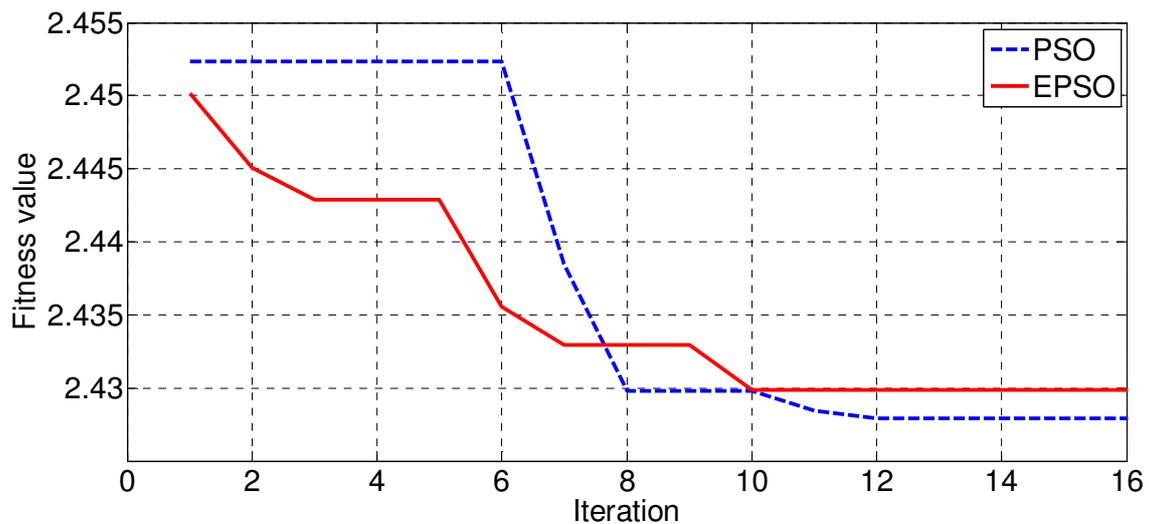


Figure 5: Convergence curve of PSO and EPSO

## 5. Conclusions

In this work, optimisation of parameter values of PID controller for load frequency control in two-area power system using two different particle swarm optimisation algorithms have been successfully proposed. From the results obtained, the proposed PID controller in load frequency control (LFC) for two-area power system yields better performance with EPSO algorithm than conventional PSO algorithm. The performance of the controller was demonstrated through the rise time and settling time of the response. It was also found that EPSO converges faster than PSO. Therefore, the proposed EPSO algorithm with a load frequency control in two-area power system has managed to improve the performance of the controller. The proposed method using optimisation algorithm in LFC also yields better results than without using optimisation methods. Future work may consider including two PID controllers in the two-area power system and using different optimisation algorithms.

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## References

- [1] H. Unbehauen, Experimental Modelling and Adaptive Power Control of a 750 MW Once-Through Boiler, *Proceedings of 11th IFAC World Congress*, Tallin, SU, Vol. 4, pp. 226-231, 13-17 August 1990.
- [2] K. Sabahi, A. Sharifi, M. Aliyari, Load Frequency control in Interconnected Power System Using Multi-Objective PID Controller, *Journal of Applied Science*, 8(20):3676-3682, 2008 ISSN 1812-5654, 2008.
- [3] C.S., Chang, W. Fu, Area load frequency control using fuzzy gain scheduling of PI Controllers, *Electric Power systems Research*, 42, pp. 145-152, 1997.
- [4] A. Kumar, O.P. Malik, G.S. Hope, Variable structure- system control applied to AGC of an Interconnected power system, *IEE Proceedings*, Vol. 132, Pt. C, No. 1, pp. 23-29, January 1985.

- [5] M.M. Ismail, Load Frequency Control Adaptation Using Artificial Intelligent Techniques for One and Two Different Areas Power System, *International Journal of Control, Automation and Systems*, Vol. 1, No. 1, January 2012.
- [6] S.J. Bassi, M.K. Mishra and E.E. Omizegba, Automatic Tuning of Proportional-Integral-Derivative (PID) controller using Particle Swarm Optimization (PSO) algorithm, *International Journal of Artificial Intelligence @ Applications (IJAIA)*, Vol. 2, No. 4, October 2011.
- [7] R. Jayanthi, I.A. Chidambaram, C. Banusri, Decentralized controller gain scheduling using PSO for Power system restoration assessment in a two-area interconnected power system, *International Journal of Engineering, Science and Technology*, Vol. 3, No. 4, pp. 14-16, 2011.
- [8] M Araki, Control systems, Robotics and Automation, *Encyclopaedia of Life Support System*, Vol. 2.
- [9] K.J. Astrom, T. Hagglund, The future of PID control, *Control Eng. Pract.*, Vol. 9, No. 11, pp. 1163–1175, 2011.
- [10] S.M.G. Kumar, PSO based Tuning of a PID Controller for a High Performance Drilling Machine, *International Journal of Computer Applications*, Vol. 1, No. 19, 2010.
- [11] D.E. Seborg, T.F. Edgar and D.A. Mellichamp, *Process Dynamics and Control*, Wiley, New York, 2004.
- [12] J. Kennedy, R.C. Eberhart, Particles Swarm Optimization, *Proc. IEEE International Conference on Neural Networks*, Perth Australia, pp. 1942-1948, 1995.
- [13] R.C. Eberhart, J. Kennedy, A New Optimizer Using Particles Swarm Theory, *Proc. Sixth International Symposium on Micro Machine and Human Science*, Nagoya-Japan, pp. 39-43, 1995.
- [14] T. Beielstein, K.E. Parsopoulos and N. Michael, Tuning PSO Parameters Through Sensitivity Analysis, *Technical Report of the Collaborative Research Center*, University of Dortmund, January, 2002.
- [15] N. Modi, M. Khare and K. Chaturvedi, Performance Analysis of Load Frequency Control in Single are Power system Using GA and PSO Based PID controller, *International Journal of Electrical, Electronics and Computer Engineering*, Vol. 2, No. 1, pp. 108-114, 2013.
- [16] H. GÖZD, M. TAPLAMACIOĞLU, İ. KOCAARSLAN, E. ÇAM, Particle Swarm Optimization Based Load Frequency Control In A Single Area Power System, *University Of Pitesti – Electronics And Computers Science, Scientific Bulletin*, Vol. 2, No. 8, 2008.
- [17] M.F. Tasgetiren and Y.C. Liang, A Binary Particle Swarm Optimization Algorithm for Lot Sizing Problem, *Journal of Economic and Social Research*, Vol. 5, No. 2, pp. 1-20, 2003.
- [18] A.P. Engelbrecht F. Bergh, A New Locally Convergent Particle Swarm Optimiser, *IEEE Conference on Systems, Man and Cybernetics*, Tunisia, 2002.
- [19] V. Miranda and N. Fonseca, EPSO-Evolutionary Particle Swarm Optimization, a New Algorithm with Application in Power Systems, *Proc. of the IEEE congress on Evolutionary Computation*, pp. 745-750, June 2002.
- [20] Y.L.A. Magid and M.M. Dawoud, Genetic algorithms applications in load Frequency control, *Genetic Algorithms in Eng. Sys. Innovations and Applications*, No. 414, 1995.
- [21] Mohd Noor Abdullah, Ab Halim Abu Bakar, Nasrudin Abd Rahim, Hazlie Mokhlis, "Modified particle swarm optimization for economic-emission load dispatch of power system operation", *Turkish Journal of Electrical Engineering & Computer Sciences*, *Turkish Journal of Electrical Engineering & Computer Sciences*, Vol. 23, Sup. 1, pp. 2304-2318, Nov 2015.
- [22] J.J. Jamian, M.W. Mustafa, H. Mokhlis, "Optimal multiple distributed generation output via rank Evolutionary particle swarm Optimization", *Neurocomputing*, Vol.152, pp. 190-198, March 2015.
- [23] H.A. Illias, X.R. Chai, A.H.A. Bakar, and H. Mokhlis, "Transformer incipient fault prediction using combined artificial neural network and various particle swarm optimisation techniques", *PLoS One*, Vol. 10, Issue 6, 2015.
- [24] M.N. Abdullah, A.H.A Bakar, N.A. Rahim, H. Mokhlis, H.A. Illias, J.J. Jamian, "Modified Particle Swarm Optimization with Time Varying Acceleration Coefficients for Economic Load Dispatch with Generator Constraints", *Journal of Electrical Engineering & Technology*, Vol.9, No. 1, pp. 15-26, January 2014.
- [25] J.J. Jamian, M.N. Abdullah, H. Mokhlis, M.W. Mustafa, and A.H.A. Bakar, "Global Particle Swarm Optimization for High Dimension Numerical Functions Analysis", *Journal of Applied Mathematics*, vol. 2014, Article ID 329193, 14 pages, 2014.
- [26] Jasrul Jamani Jamian, Hazlie Mokhlis, Mohd Wazir Mustafa, Mohd Noor Abdullah, Muhammad Ariff Baharuddin, "Comparative Learning Global Particle Swarm Optimization for Optimal Distributed Generations' Output", *Turkish Journal of Electrical Engineering & Computer Sciences*, Vol. 22, No. 5, pp.1323-1337, Sept 2014.
- [27] M.M. Aman, G.B. Jasmon, A.H.A. Bakar, H. Mokhlis, "A new approach for optimum simultaneous multi-DG distributed generation Units placement and sizing based on maximization of system loadability using HPSO (hybrid particle swarm optimization) algorithm", *Energy*, Vol.66, pp. 202-215, March 2014.
- [28] Mohd Noor Abdullah, Ab Halim Abu Bakar, Nasrudin Abd Rahim and Hazlie Mokhlis, "Economic load dispatch with nonsmooth cost functions using evolutionary particle swarm optimization", *IEEJ Transactions on Electrical and Electronic Engineering*, Vol.8, Issue S1, Pages S30-S37, Nov 2013.