Particle Swarm Optimization Based LFC and AVR of Autonomous Power Generating System

A.Soundarrajan, *Member, IAENG*, Dr.S.Sumathi, C.Sundar

Abstract - **In this paper, an evolutionary computing approach for determining the optimal values for the proportional-integral-derivative (PID) controller parameters of load frequency control (LFC) and Automatic Voltage Regulator (AVR) system of single area power system using the particle swarm optimization technique is presented. The LFC loop controls real power & frequency and AVR loop controls reactive power and voltage. Due to rising and falling power demand, the real and reactive power balance is harmed; hence frequency and voltage get deviated from nominal value. This necessitates designing of an accurate and fast controller to maintain the system parameters at nominal value. The main purpose of system generation control is to balance the system generation against the load and losses so that the desired frequency and power interchange between neighboring systems are maintained. This work demonstrates the application of PSO method to search efficiently optimal PID controller parameters of LFC and AVR system. The proposed method had superior features like, stable convergence characteristics, easy implementation and good computational efficiency. The simulation results demonstrate the effectiveness of the designed system in terms of reduced settling time, overshoot and oscillations. The results are compared with conventional PID , Fuzzy and GA based controllers.**

Key Words - **Automatic Voltage Regulator (AVR), Load Frequency Control (LFC), Evolutionary Computation (EC), Particle Swarm Optimization (PSO).**

I. INTRODUCTION

In recent years electricity has been used to power more sophisticated and technically complex manufacturing processes, computers and computer networks, operation theatres in hospitals and a variety of other high-technology consumer goods. These products and processes are sensitive not only to the continuity of power supply but also on the quality of power supply such as voltage and frequency.

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A.Soundarrajan is working as Senior Lecturer in Department of Information Technology, PSG College of Technology, Coimbatore-641004, India. (91-9942069911, Fax: 91-422-2573833, soundaa@yahoo.com).
Dr.S.Sumathi is working as Assistant Professor in Electrical and Electronics Engineering Department, PSG College of Technology, Coimbatore-641004, India (ssi@eee.psgtech.ac.in)
C.Sundar was a UG student in Electrical and Electronics Engineering Department, PSG College of Technology, Coimbatore-641004, India. He is now with Chennai Petroleum Corporation Limited, Chennai, Tamilnadu, India (csundar@cpcl.co.in).

In power system, both active and reactive power demands are never steady they continuously change with the rising or falling trend. Steam input to turbo generators(or water input to hydro generators) must therefore, be continuously regulated to match the active power demand, failing which the machine speed will vary with consequent change in frequency, which may be highly undesirable. In brief, the changes in real power affect the system frequency, while reactive power is less sensitive to changes in frequency and is mainly dependent on changes in voltage magnitude. The quality of power supply must meet certain minimum standards with regard to constancy of voltage and frequency. The function of excitation control is to regulate generator voltage and reactive power output. The desired real power outputs of the individual generating units are determined by the system generation control. The voltage and frequency controller has gained importance with the growth of interconnected system and has made the operation of power system more reliable. Many investigations in the area of LFC and AVR of an isolated power system have been reported and a number of control schemes like Proportional and Integral (PI), Proportional, Integral and Derivative (PID) and optimal control have been proposed to achieve improved performance [1-3]. The conventional method exhibits relatively poor dynamic performance as evidenced by large overshoot and transient frequency oscillations.[4] These conventional fixed gain controllers based on classical control theories in literature are insufficient because of change in operating points during a daily cycle.[5,6].

Several new optimization techniques like Genetic Algorithm (GA), PSO, Ant Colony Optimization (ACO), Simulated Annealing (SA) and Bacterial Foraging have emerged in the past two decades that mimic biological evolution, or the way biological entities communicate in nature.[7]. Due its high potential for global optimization, GA has received great attention in control system such as the search of optimal PID controller parameters. The natural genetic operations would still result in enormous computational efforts. The premature convergence of GA degrades its performance and reduces its search capability. Particle swarm optimization (PSO), first introduced by Kennedy and Eberhart, is one of the modern heuristics algorithms. It was developed through simulation of a simplified social system, and has been found to be robust in solving continuous non-linear optimization problems. Researchers including Zwe-Lee Gaing have presented PSO for optimum design of PID controller in AVR system.[8].

A new time-domain performance criteria function was defined to estimate their system. To improve the performance of the PID controller, You-bo wang et al have presented the use of new PSO based auto tuning of PID controllers.[9] (You-Bo). Haluk gozde et al has used the PSO algorithm for optimizing PID values of LFC in a single area power system. [10] (Haluk gozde). Their contribution includes selection of optimum parameter value for the integral gain and proportional gain was made equal to the regulation R. All these works have been reported for implementing intelligent techniques for controlling voltage and frequency separately. Hence, a novel approach of combined intelligent control of voltage and frequency in a single area power system is proposed in this paper. The objective of this work is to design and implement PSO-PID controller to search the optimal parameter for efficient control of voltage and frequency. The model of the LFC and AVR of single area power system is designed using simulink in MATLAB. The PSO algorithm was developed to generate the optimum Proportional, Integral and Derivative gains of the controller. These values are sent to workspace and shared with the simulink model for simulation under different loads and regulation parameters. The proposed LFC and AVR contribute to the satisfactory operation of the power system by maintaining system voltages and frequency.

The paper is organized as follows, Section 2 describes the model of the plant including LFC and AVR, Section 3 describes the design of Fuzzy controller, Section 4 demonstrates the simulation results, Section 5 shows the comparison of PSO-PID controller with conventional PID, fuzzy and GA and conclusion is derived in Section 6.

II. LINEARIZED MODEL OF THE PLANT

A. Basic Generator Control Loops

In an interconnected power system, LFC and AVR equipment are installed for each generator. The schematic diagram of the voltage and frequency control loop is represented in fig.1. The controllers are set for a particular operating condition and take care of small changes in load demand to maintain the frequency and voltage magnitude within the specified limits [11].

Small changes in real power are mainly dependent on changes in rotor angle δ and, thus, the frequency f. The reactive power is mainly dependent on the voltage magnitude (i.e. on the generator excitation). Change in angle δ is caused by momentary change in generator speed. Therefore, load frequency and excitation voltage controls are non-interactive for small changes and can be modeled and analyzed independently. Furthermore, excitation control is fast acting while the power frequency control is slow acting since, the major time constant contributed by the turbine and generator moment of inertia-time constant is much larger than that of the generator field. Thus, the cross-coupling between the LFC loop and the AVR is negligible, and the load frequency and excitation voltage control are analyzed independently.

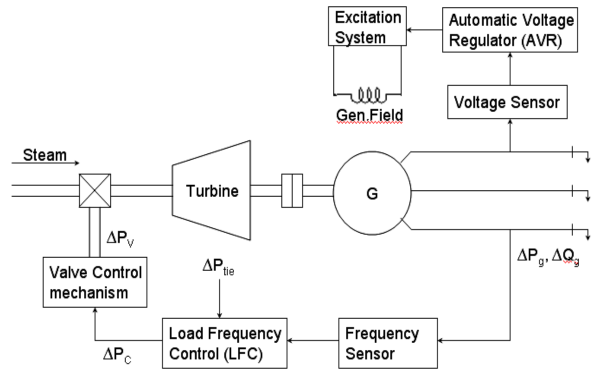

Fig 1 Schematic diagram of LFC and AVR of a synchronous generator

B. Load frequency Control (LFC)

The aim of LFC is to maintain real power balance in the system through control of system frequency. Whenever the real power demand changes, a frequency change occurs. This frequency error is amplified, mixed and changed to a command signal which is sent to turbine governor. The governor operates to restore the balance between the input and output by changing the turbine output. This method is also referred as Megawatt frequency or Power-frequency (P-f) control [11].

C. Automatic Voltage regulator (AVR)

The aim of this control is to maintain the system voltage between limits by adjusting the excitation of the machines. The automatic voltage regulator senses the difference between a rectified voltage derived from the stator voltage and a reference voltage. This error signal is amplified and fed to the excitation circuit. The change of excitation maintains the VAR balance in the network. This method is also referred as Megawatt Volt Amp Reactive (MVAR) control or Reactive-Voltage (QV) control. The simulink models of load frequency controller and automatic voltage regulator is constructed based on the block diagram approach as proposed by Hadi Sadaat.[12]. The Proportional, Integral and Derivative controller is included in LFC and AVR. The models of LFC and AVR with PID controller are shown in Fig.2 and Fig.3, respectively

II. DESIGN OF EVOLUTIONARY CONTROLLER

Evolutionary Computation (EC) is developed from the principle of the ‘survival of the fittest’ proposed by Charles Darwin in 1859 and the term Evolutionary Computation was invented as recently as 1991.It is a meta-heuristic method and a biologically inspired search and optimization methodology. An EC technique abstracts the evolutionary principles into algorithms that are used to

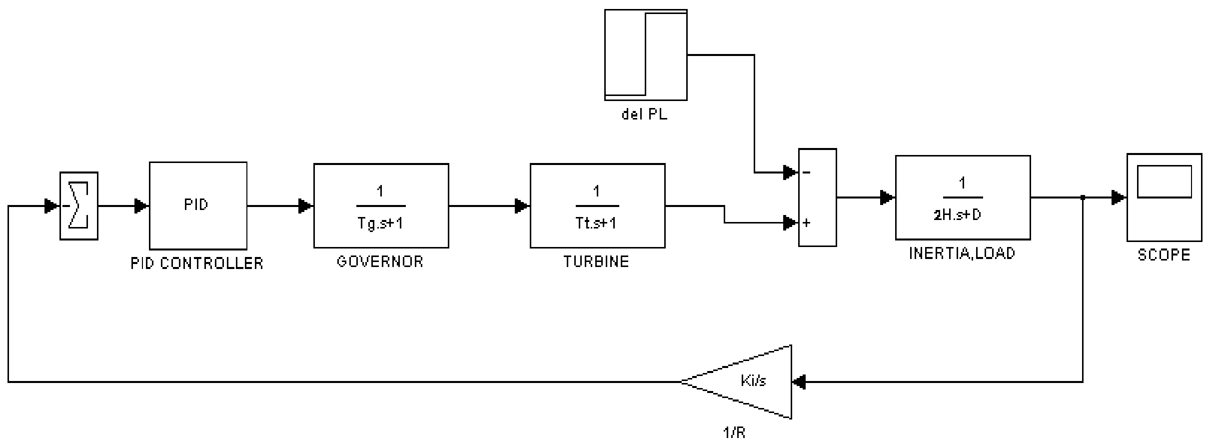

Fig.2 Simulink model of LFC with PID Controller

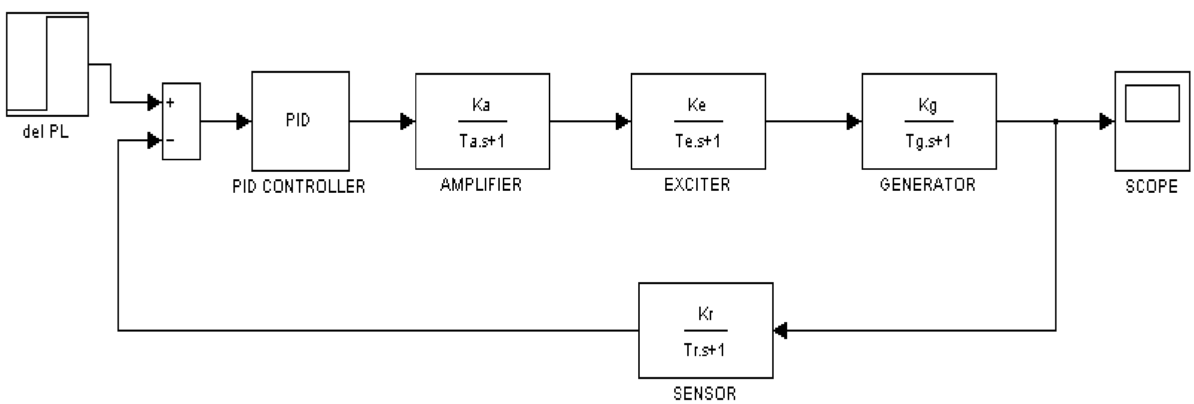

Fig.3 Simulink model of AVR with PID Controller

search for optimal solutions to a problem. In this algorithm, a number of possible solutions to a problem are available and the task is to find the best solution.EC creates a search space which contains the randomly generated solutions and finds the optimum solution from the search space.

Since the components of a power system are non linear, a linearized model around an operating point is used in the design process of LFC and AVR controllers. However, controllers based on linearized models are not capable of supporting parameter variations for stability. When the process becomes too complex to be described by analytical models, it is unlikely to be efficiently controlled by conventional fixed gain controllers. Conventional proportional–integral–derivative (PID) controllers have been well developed and are extensively used for industrial automation and process control.[13] The main reason is due to their simplicity of operation, ease of design, inexpensive maintenance, low cost, and effectiveness for most linear systems. However, it has been known that conventional PID controllers generally do not work well for nonlinear systems, higher order and time-delayed linear systems, and particularly complex and vague systems that have no precise mathematical models [14,15] . Hence, an evolutionary PSO-PID controller is proposed in this paper to control the voltage and frequency for different load conditions and regulation. In this paper, PSO based PID controller is designed and implemented to overcome the drawback of conventional fixed gain controllers.

A. Particle Swarm Optimization (PSO)

PSO is a stochastic Evolutionary Computation technique based on the movement and intelligence of swarms. The original PSO algorithm is discovered through simplified social model simulation. PSO algorithm combines both cognitive behavior and social cooperation of birds. The bird follows the shortest path for searching the food. Based on this behavior of the birds, PSO algorithm is developed.[16] It was originally developed for nonlinear optimization problems with continuous variables. However, it is easily expanded to treat problems with discrete variables. Therefore, it is applicable to mixed integer nonlinear optimization problems with both continuous and discrete variables. In the search space each particle acts individually and accelerates toward the best personal location (p_{best}) while checking the fitness value of its current position. Fitness value of a position is obtained by evaluating the so-called fitness function at that location. If a particles' current location has a better fitness value than that of its current p_{best}, then the p_{best} is replaced by the current location. [17- 18]

Each particle in the swarm has knowledge of the location with best fitness value of the entire swarm which is called the global best or g_{best}. At each point along their path, each particle also compares the fitness value of their p_{best} to that of g_{best}. If any particle has a p_{best} with better fitness value than that of current g_{best}, then the current g_{best} is replaced by that particle's p_{best}. The movement of particles is stopped once all particles reach sufficiently close to the position with best fitness value of the swarm.

B. Implementation of PSO-PID Controller

This paper presents a PSO-PID controller for searching the optimal controller parameters of LFC and AVR. In PSO algorithm, each particle in the swarm represents a solution to the problem and it is defined with its position and velocity [19-21]. In D-dimensional search space, the position of the *i*th particle can be represented by a D-dimensional vector, $X_i = (X_{i1},\ldots, X_{id}, \ldots, X_{iD})$. The velocity of the particle v_i can be represented by another *D*-dimensional vector $V_i = (V_{i1},\ldots, V_{id}, \ldots, V_{iD})$. The best position visited by the *i*th particle is denoted as $P_i=(P_{i1},\ldots,P_{id},\ldots,P_{iD})$, and P_g as the index of the particle visited the best position in the swarm, then P_g becomes the best solution found so far, and the velocity of the particle and its new position will be determined according to the following equations.

$$V_{id} = WV_{id} + C1\,R\,(P_{id} - X_{id}) + C2\,R\,(P_{gd} - X_{id}) \quad (1)$$

$$X_{id} = X_{id} + V_{id} \quad (2)$$

C1 and C2 are the cognitive and social coefficients. R is the random number generated between 0 and 1. The parameter W in equation (1) is inertia weight that increases the overall performance of PSO. It is reported that a larger value of W can favor higher ability for global search while lower value of W implies a higher ability for local search. To achieve a higher performance, we linearly decrease the value of inertia weight W over the generations to favor global search in initial generations and local search in the later generations. The linearly deceased value of inertia is according to the equation.

$$W = Wmax - \frac{Wmax - Wmin}{Iter\ max} \times iter \quad (3)$$

Where $iter_{max}$ is the maximum of iteration in evolution process, W_{max} is maximum value of inertia weight, W_{min} is the minimum value of inertia weight, and iter is current value of iteration. The variables which are used in PSO algorithm and their definitions are given in appendix 1.

The design steps of PSO based PID controller is as follows.

1. Initialize the algorithm parameters like number of generation, population, inertia weight and constants.
2. Initialize the values of the parameters K_P, K_i and K_D randomly.
3. Calculate the fitness function of each particle in each generation.
4. Calculate the local best of each particle and the global best of the particles.
5. Update the position, velocity, local best and global best in each generation.
6. Repeat the steps 3 to 5 until the maximum iteration reached or the best solution is found.

The objective function represents the function that measures the performance of the system. The fitness function (objective) function for PSO is defined as the Integral of Time multiplied by the Absolute value of Error (ITAE) of the corresponding system. Therefore, it becomes an unconstrained optimization problem to find a set of decision variables by minimizing the objective function.[22].

C. Simulink model of PSO Based PID Controller

To verify the efficiency of proposed algorithm a practical higher order system in Fig.4 is considered. The PSO algorithm is used to search an optimal parameter set containing K_p, K_i and K_d. The optimum values generated by the algorithm are stored in work space and shared with the LFC and AVR simulink model. The parameters used for tuning the PSO algorithm and simulink models are tabulated in table.1 & 2.

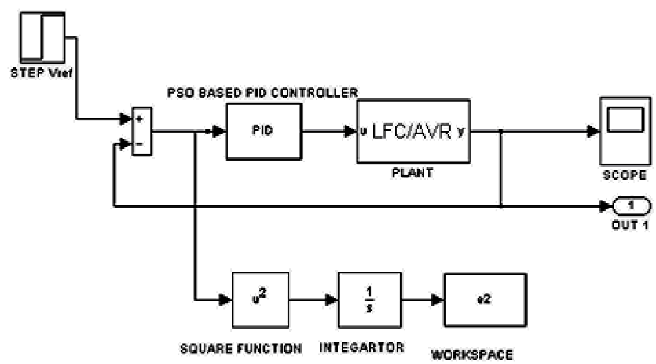

Fig.4 Simulink model of a plant with PSO Algorithm based PID Controller

Table.1 LFC and AVR simulation parameters

	Simulation Parameters
LFC	Tg = 0.095, Tt = 0.5, H = 10, D = 0.8, R = 100,125 ΔP_L = 0.10, 0.20
AVR	Ka =1.1165, Ta =0.2, Te = 0.4, K_f= 0.75, T_f=1.4, K_R= 1, T_R = 0.05

The PSO algorithm was simulated and tested by tuning the various parameters like population size, inertia weight and acceleration factor. The optimum parameter values that achieved better solution are listed in Table 2.[18-20]

Table. 2 PSO Parameters

Parameters	LFC	AVR
Population size	5	50
Number of generations	10	50
Inertia weight (w)	0.8	0.9
cognitive coefficient (C1)	2.05	2.0
social coefficient (C2)	2.05	2.0

IV. SIMULATION RESULTS

The simulation was done using the simulink package available in MATLAB 7.1. The LFC and AVR were simulated on Pentium 4 (2.4 MHz), 1GB RAM desktop PC. The LFC and AVR are simulated using PSO based PID controller, for different values of load and regulation. The simulation time was set to 100seconds and 20seconds for AVR and LFC respectively. The terminal voltage response for a change in load of 0.1 p.u and regulation of 10 is shown in Fig.5.

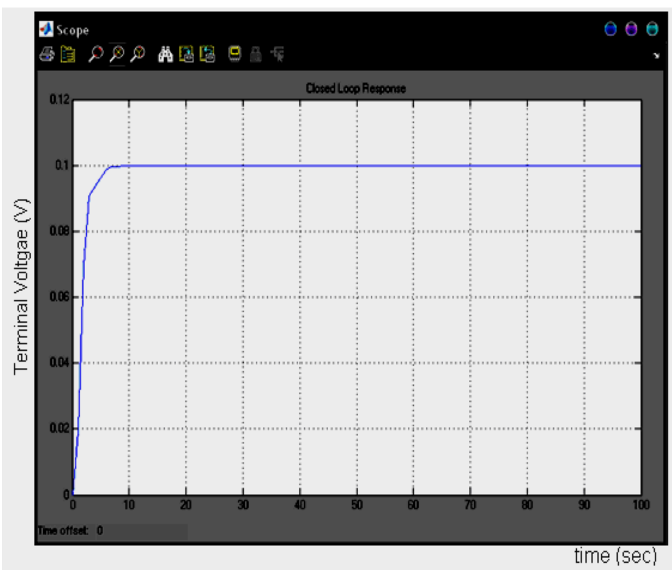

Fig.5 AVR with PSO based PID controller for R=10 and $\Delta P_L = 0.1$ p.u

It is observed that the settling time of AVR with PSO based PID controller is 9 seconds and there is no transient peak overshoot. As seen from the result, the PSO-PID controller could create very perfect step response of the terminal voltage in AVR system. Similarly the LFC model was simulated with different loads and regulations. The change frequency for a load of 0.1 p.u and regulation 'R' value as 10 is shown in fig.6.

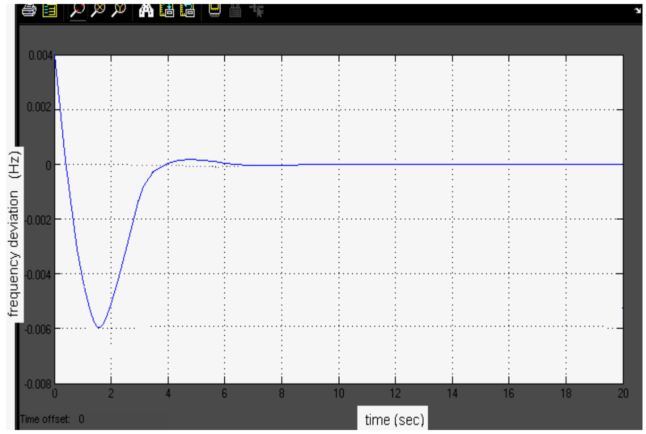

Fig.6 LFC with PSO based PID controller for R=10 and $\Delta P_L = 0.1$ p.u

It is inferred that the settling time of LFC with PSO based PID controller is 8.2 seconds and the peak overshoot is -0.006. These results clearly indicate that the proposed controller can search optimal PID controller parameters quickly and efficiently. In order to emphasize the advantage of the proposed controller the surface plot and contour mapping of the frequency response characteristics is shown in Fig.7.

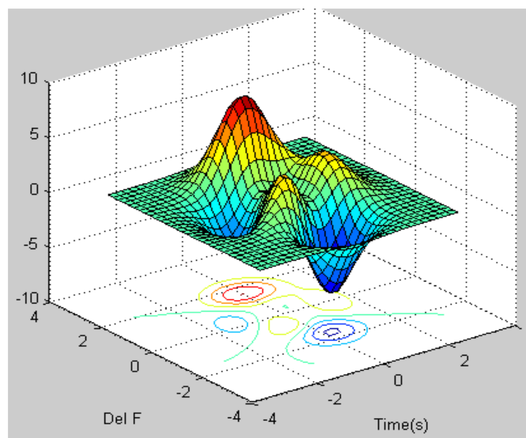

Fig. 7 Surface plot of PSO-PID based LFC

In order to demonstrate the effectiveness of the proposed controller, simulations are carried out by varying the load and regulation. The value of determines the slope of the governor characteristics and it determines the change on the output for a given change in frequency. In practice 'R' is set on each generating unit so that change in load on a system will be compensated by generated output. The speed governor system should be operated within the restricted control range of feedback gains due to the system instability. So, higher the value of load ΔPL for a small 'R' value will introduce oscillations into the system. Hence ΔPL and R are selected as shown in table 3 & 4 to obtain optimum results in terms of settling time, overshoot and oscillations. Increasing the load ΔPL into higher values will experience large overshoot and settling time. The results which showed the best solution was summarized in table 3.& 4 with change in load of 0.1 and 0.2 for a regulation value 10 and 20.Hence the results indicates the efficiency of PSO algorithm for real-time applications and its suitability under varying load conditions.

Table. 3 Performance Analysis of PSO based PID Controller for AVR

Parameters	R1=10		R2=20	
	ΔP_L=0.1	ΔP_L=0.2	ΔP_L=0.1	ΔP_L=0.2
Settling Time(sec)	9	11.2	8.82	9.3
Overshoot(Hz)	0	0.22	0	0.204
Oscillation(Hz)	0 to 0.1	0 to 0.22	0 to 0.1	0 to 0.204

Table 4 Performance Analysis of PSO based PID Controller for LFC

Parameters	R1=10		R2=20	
	ΔP_L=0.1	ΔP_L=0.2	ΔP_L=0.1	ΔP_L=0.2
Settling Time(sec)	8.2	8.34	10.3	10.42
Overshoot (Hz)	-0.006	-0.0213	-0.0147	-0.0076
Oscillation (Hz)	0 to 0.006	0 to 0.0213	0 to -0.0147	0 to 0.007

V. COMPARATIVE ANALYSIS

A comparison on dynamic performances between various controllers for LFC and AVR are represented in table 5 & 6. The settling time, oscillations and overshoot are compared for a load change of 0.10 and regulation of 10. It is observed from the table that the designed PSO-PID controller exhibits relatively good performance with very less settling time, overshoot and transient oscillations. The main advantage of PSO approach when compared to GA, is that PSO does not have genetic operators such as crossover and mutation. Particles update themselves with the internal velocity and tend to converge to the best solution quickly.[22-24] The results prove that PSO method has better efficiency in solving power system optimization problem.

Table 5 Performance Comparison of PSO based AVR with Conventional AVR

Fixed Parameters: K_a= 10 , T_a= 0.1 , K_e= 1, T_e= 0.1, k_g= 1 , T_g = 1, K_r= 1 , T_r= 0.05			
Methods	**Settling Time (sec)**	**Overshoot(Hz)**	**Oscillations(Hz)**
Conventional PID	37.5	0	0 to 0.1
Fuzzy Controller	16	0	0 to 0.1
GA-PID	11.38	0	0 to 0.1
PSO-PID	8.82	0	0 to 0.1

Table 6 Performance Comparison of PSO based LFC with Conventional LFC

Fixed Parameters: T_g= 0.2 , T_T=0.5 ,k_g=1 , H = 5,D=0.8			
Methods	**Settling Time (sec)**	**Overshoot(Hz)**	**Oscillations(Hz)**
Conventional PID	51	-0.0083	0 to 0.0083
Fuzzy Controller	20	-0.0052	0 to -0.0052
GA-PID	10.25	-0.0026	1.5919e006 to -0.0026
PSO-PID	8.2	-0.0014	0 to -0.0014

The bar chart in the Fig.8 shows the comparative analysis made between different controllers like conventional PID, Fuzzy, GA and PSO. Comparison has been made with respect to settling time, oscillations and overshoot. When an electrical load change occurs, the turbine-generator rotor accelerates or decelerates, and frequency undergoes a transient disturbance. The controller should not allow transient oscillations or overshoot, which in-turn trips the under-frequency relay connected in the system. Oscillations, settling time and overshoot are all related: change in one will cause a change in others. Hence, it is important that the designed controller must be efficient in selecting the optimum gains in order to achieve better results. The LFC and AVR with proposed PSO based controller shows enhanced performance characteristics wrt settling time, oscillations and overshoot when compared to conventional controllers. The settling time, oscillations and overshoot of the LFC with PSO based controller is reduced by 84%, 83.2% and 83.2%, respectively. The settling time of AVR with PSO based controller is decreased by a factor of 77%..

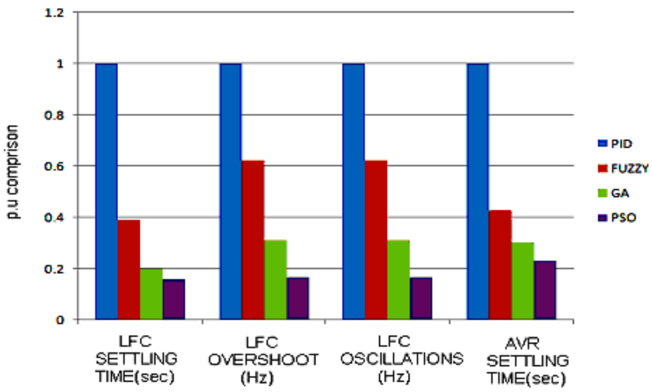

Fig.8 Comparative Analysis of Conventional controllers with PSO based controller for LFC and AVR

6. CONCLUSIONS

The quality of the power supply is determined by the constancy of frequency and voltage. Minimum frequency deviation and good terminal voltage response are the characteristics of a reliable power supply. The conventional controllers used for this problem have large settling time, overshoot and oscillations. Hence, when evolutionary algorithms are applied to control system problems, their typical characteristics show a faster and smoother response. An intelligent technique has been proposed for combined voltage and frequency control in an isolated power system. The proposed PSO-PID controller provides a satisfactory stability between frequency overshoot and transient oscillations with zero steady state error. The simulation results demonstrate the effectiveness of the proposed controller under changing loads and regulations. The work can be extended in future by including non-linear parameters to the system modeled and thereby comparison can be made with respect to linear system. Also the other evolutionary computing techniques like Hybrid Particle Swarm optimization (PSO), GA-PSO, Hybrid GA, Fuzzy PSO, Distributed Evolution etc., can be implemented to improve the performance characteristics.

APPENDIX 1:

Variables and their definitions used in PSO algorithm

Variable	Definition
itermax	Maximum number of iteration
X_i	Position of ith particle
V_i	Velocity of ith particle
P_i	Best position previously visited by ith particle
P_g	Best position visited by a particle
W	Inertia weight
C_1 & C_2	Cognitive coefficient & Social coefficient
R and r	Random number between 0 and 1

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A.Soundarrajan is a member of IAENG from 2007. The author was born in Coimbatore, Tamilnadu, India on 23.06.1973. And has received his BE in Electrical and Electronics Engineering in 1999 from Coimbatore Institute of Technology, and ME in Applied Electronics in 2003 under Quality Improvement Program from PSG College of Technology, Coimbatore, India. And is currently pursuing research in Electrical and Electronics Engineering department of PSG College of Technology.

He is currently working as SENIOR LECTURER in Department of Information Technology, PSG College of Technology, Coimbatore, INDIA. He has over 10 years of teaching experience and 6 years of industrial experience. His current research interest includes application of evolutionary algorithms and optimization in electrical power systems.

Mr.A.Soundarrajan is a life member of Indian Society for Technical Education and also member since 2009 in International association of Computer Science and Information Technology.

Dr.S.Sumathi was born in Coimbatore, Tamilnadu, India. Received her BE and ME degrees from Government College of Technology, Coimbatore, India, in 1988 and 1990 respectively. Received Ph.D degree from PSG College of Technology under Anna University, Chennai in 2002.
She is currently working as an ASSISTANT PROFESSOR in Department of Electrical and Electronics Engineering, PSG College of Technology, Coimbatore, INDIA, since 1990. Her publication includes, Fundamentals of Relational Database Management Systems, Germany, Springer, 2007, Introduction to Fuzzy Logic using MATLAB, Germany, Springer, 2007, Introduction to Data Mining and its Applications, Germany, Springer, 2006. Her current research interest includes Soft Computing, Artificial Intelligence, Evolutionary Algorithms, Database management systems, Data Mining and Image Processing.

Mr.C.Sundar was born in Coimbatore, Tamilnadu, India. Received his BE degree in Electrical and Electronics Engineering in 2009 from PSG College of Technology, Coimbatore, India.
He is currently working as an ENGINEER in Chennai Petroleum Corporation Ltd,. Manali, Tamilnadu, India.