PSO based Load Frequency Control of Hybrid Power System

[1]Paturi Radhika,[2]Peddisetti Sivakumari ,[3]Kammili Sirisha

[1]Lecturer in Physics, [2]Lecturer in Physics, [3]Lecturer in Physics

[1, 2, 3] SIR C R Reddy College for Women, Eluru, Andhra Pradesh, INDIA

Abstract: Recent studies suggest that in the next five decades, large portion of the NonRenewable sources accessible will be diminishing. This is the prime concern for attracting the attention for the enhancement in the performance of the renewable energy sources which abundantly exist in the nature. Wind, solar photovoltaic, and solar thermal power systems are emerging renewable technologies that can be developed as a viable option for the future generation of electrical energy. In this paper, we have considered a hybrid power system consisting of Wind turbine generator (WG), solar photovoltaic (S-PV), diesel generator (DG), fuel cell (FC), battery energy storage system (BES) and aqua electrolyzer (AE) for simulation studies. The main purpose of controller is to maintain the frequency of the grid to nominal values, for any deviations in these nominal values are due to sudden variations in load or generator or both. To maintain frequency stability of the system we employ controllers designed through conventional methods which is vary tedious and time consuming process,with the introduction of computational techniques opened a new path way for advanced new generation controllers. In this paper PSO (Particle swarm optimization) based PI controller is maintained to regulate frequency deviations. From the results, we can demonstrate the effectiveness of the PSO based controllers in terms of reduced settling time, over shoot, and oscillations. The results are compared with conventional controllers and with the controllers whose gains are tuned by GA (Genetic Algorithm).

Index Terms – **Load Frequency controller, Particle Swarm Optimization, Genetic Algorithm, Hybrid power system.**

I. INTRODUCTION

Electricity plays a vital role in all the aspects of human life. With increasing trends in technology demands more power to be generated through fossil fuel. Thus this increase in power demand leads to ecological imbalance such as increase in carbon emission and global warming. These shifting trends of technology required the necessity for clear, ecofriendly and sustainable energy. Research shifted to the alternative generation sources which are available abundantly in nature such as wind, solar, geo-thermal, tidal, bio-mass, are some of the sustainable green energy sources. Among all the available renewable sources wind and solar are more trending as they have high potential and good efficiency with considerable cost when compared to others. Fuel cell and ultra-capacitors also exhibit similar characteristics and can be considered as green sustainable sources for the future [1]. The hybrid system not only delivers load demand but also includes energy storage systems in the form of batteries. Through this system we can deliver both AC and DC power. Thus, by using proper equipment we regulate the overall performance of the system[2].

The design part of the controller includes both conventional methods and soft computing techniques, such as genetic algorithm, differential evaluation, particle swarm optimization etc., are used to calculate the gains of the controller. The above stated methods were limited to conventional systems but never applied for hybrid systems for optimization of gains for the controllers [3]. In hybrid systems, the controllers generally used are proportional plus integral (PI) which regulates the output power to achieve power equilibrium condition due to abrupt increase in loads and generation. We employ trial and error method described by Ziegler and Nichols to determine the gain values for the conventional PI controller to achieve better balance. This conventional method was not suitable since the gains obtained by this method are suitable for limited operating points. With increase in the number of optimization parameters the conventional controllers does not meet the required robust performance which is certainly not desired [4]. In this paper, the gains for the PI controller are obtained through PSO technique, along with the conventional and GA based gains.The intelligent control strategy provides robust adaptive response with varying parameters like non-linearity, load disturbances.

II. MODEELING OF THE POWER SYSTEM

The proposed hybrid model block diagram is illustrated in the Fig. 1. The parameters of the hybrid model are tabulated in table.1. The hybrid system is a combined model of wind turbine system, diesel generator, fuel cell(Fc), aqua electrolyzer(Ae), solar thermal and solar photovoltaic, and battery energy storage model. The load demand supplied is the summation of all the output

powers form wind, solar, fuel cell and battery storage system [5]. As wind is a varying system the fluctuations are absorbed by the aqua electrolyzer system producing the hydrogen gas which is taken as fuel for Fc system. The mathematical modeling of the hybrid system involves first order transfer functions of as shown in this section.

The data collection period is ranging from January 2010 to Dec 2014. Monthly prices of KSE -100 Index is taken from yahoo finance.
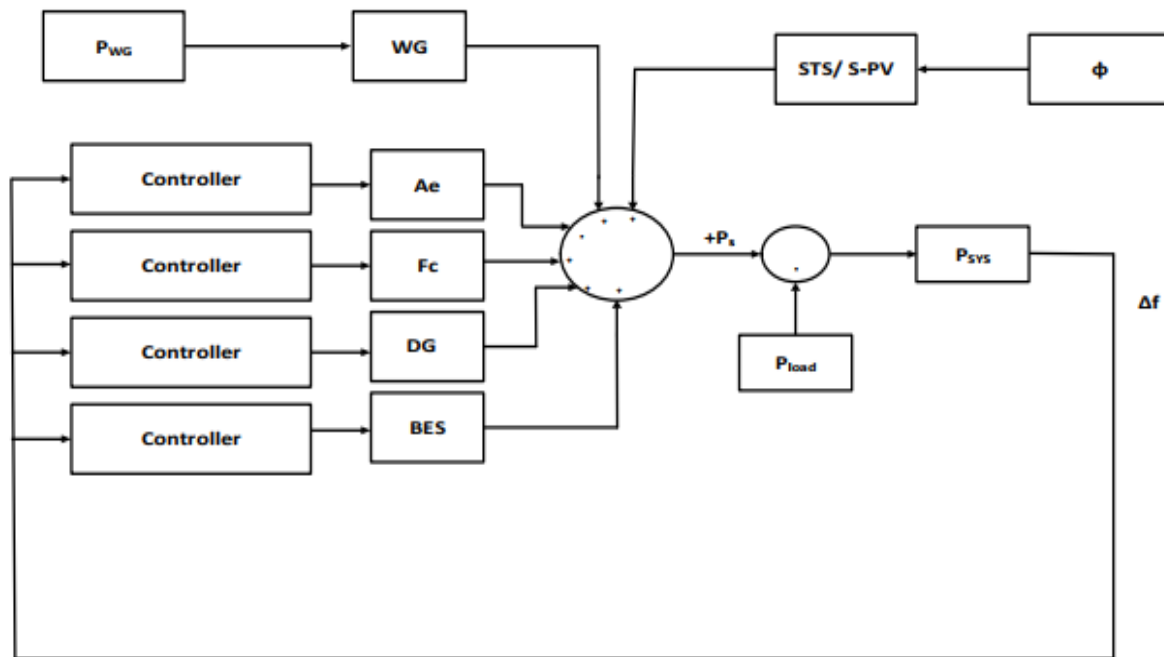

Fig.1.Bloack Diagram of Hybrid Power System

2.1 Wind Turbine Generator Model

Wind is a naturally available fuel and can be used to produce clean and sustainable power. As the speed of the wind varies with time we cannot rely on the system directly as all the systems we use require constant power supply which can be achieved by speed regulation. The Single order transfer function model of wind turbine generator is given by

$$G_{WG}(s) = \frac{K_{WG}}{T_{WG}s+1}$$

2.2 Solar PV Model

Solar energy is abundantly available in the nature in the form of light; this energy once harvested can deliver a reliable power to the system which is clean energy. In the recent years with improvement in technological constraints the solar thermal power industry is rapidly emerging as a new trend. The reduced first order lag transfer function for the solar PV model is given as.

$$G_{S-PV}(s) = \frac{K_{S-PV}}{T_{S-PV}s+1}$$

2.3 Diesel Generator Model

Diesel generators are the mostly used generation systems off grid, the torque produced in the machine drives the synchronous generator machine producing the electrical output. In diesel system the output power directly depends on the rotor shaft speed which is inversely proportional to the load demand. The simplified first order transfer function for the Diesel system with time varying non linearity is given by

$$G_{DG}(s) = \frac{K_{DG}}{T_{DG}s+1}$$

2.4 Aqua Electrolyzer Model

Aqua electrolyzers are mainly designed in the power system model to absorb the rapidly fluctuating output power from wind and solar thermal system, which generate the hydrogen required by the fuel cell system by electro conducting water and decomposing it into hydrogen and oxygen. The transfer function model for the aqua electrolyzer can be expressed by

$$G_{Ae}(s) = \frac{K_{Ae}}{T_{Ae}s+1}$$

2.5 Fuel Cell Model

The output of a typical fuel cell is a DC voltage which should be converted to AC for grid usage through semi-conductor devices such as dc/ac converters. For large usage, large numbers of fuel cells are to be connected in series and parallel circuits forming a Fuel cell stack. The higher order function of the system consists of non-linearity, thus we consider a low order lag transfer function for analyzing the low frequency domain model and is given as

$$G_{Fc}(s) = \frac{K_{Fc}}{T_{Fc}s+1}$$

2.6 Battery Energy Storage System Model

The fluctuations in the grid power even for a short time causes adverse effect of the load connected to the grid. These fluctuations can be regulated by providing an alternative solution which is possibly storage of wind energy. Battery energy storage systems are considered to be very advantageous due to their very good characteristics such as large energy density, fast access time, we can store large amount of wind energy. The transfer function model of the BESS model is represented in the first order form as

$$G_{BES}(s) = \frac{K_{BES}}{T_{BES}S+1}$$

III. PARTICLE SWARM OPTIMIZATION

In the recent years many soft computing were developed based on different animals and particles behaviors that are available in nature, which were proved to be effective in analyzing and unraveling problems [6]. Particle Swarm Optimization (PSO) is one such novel population based technique, developed in 1995 by Dr. Russel Eberhart and Dr. James Kennedy, Inspired by the swarming collaborative behavior of the flock of birds or fish schooling, when analyzed PSO with evolutionary computation techniques such as Genetic Algorithm (GA) it shares many similarities. The technique is better understood once we know the behavior of birds when searching for food in an open environment [7]. The algorithm begins with initializing a random population initially; with these initial values we try to determine the best values among the population. Once we determine the best values for the population known as 'P best', we then determine the best value among these local values and call it as 'G best' where Pbest is the best fitness value achieved so far by the particles and Gbest is the best value tracked by PSO so far obtained by any particle in the population. Once these two values are determined then the values are updated for the next iteration and again same procedure is followed until we obtain the best optimized values of the particle [8-9]. Once the Pbest and Gbest are determined, we use these values to calculate the velocity and position of particle using mathematical expressions. Once determined, the algorithm is repeated for much iteration until the criterion is met.

The steps of the PSO PID controllers are summarized as follows:

Step 1: Create the initial population for initializing the optimization for parameters (K_P,K_i,K_d). Each parameter in the problem area is a particle thus the velocity and position represents the solution to the problem.

Step 2: The objective function considered here for minimizing frequency deviations is integral square error (ISE), we calculate the J values using matlab model.

Step 3: Evaluation of the fitness function. The degree of fitness is evaluated based in the criterion. Since PSO is a minimization function, the objective function is the fitness function.

Step 4: Generating the Pbest and Gbest values for the initial iteration the values are updated for the next iterations and the final values for updating the velocity and position.

Step 5: Replace the present population with a new set of population.

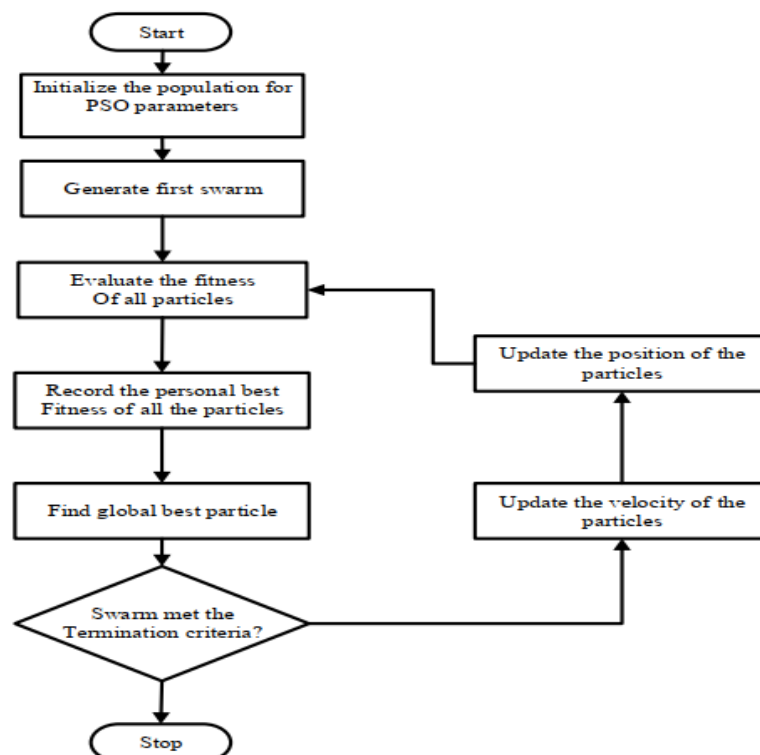Step 6: On reaching the final criterion terminate; else go to step 2

Fig.2: Flowchart of PSO Algorithm

IV. OBJECTIVE FUNCTION

In PI controller design method, the most common objective function are integral absolute error (IAE) , integral of time weight square error (ITSE), integral square error (ISE), etc. here in this model we have considered Integral Square Error (ISE) as our objective function to reduce the frequency deviations.

$$J = \int_0^\alpha (\Delta f)^2 \, dt \cdot$$

Minimize J

Subjected to

$$K_p^{min} < k_p < k_p^{max}$$

$$K_i^{min} < k_i < k_i^{max}$$

Case	sub-systems	simulation time	operating conditions
1	WG, STS, DG, Ae, Fc, BES and load	200	P_{WG} = 0.5 P.u at 0 < t <40 s 0.4 P.u at t > 40 s P_{STS} = 0.36 P.u at 0< t <40 s 0.18 P.u at t > 40 s P_L = 1 P.u at 0 < t < 80 s 1.1 P.u at t > 80 s
2	WG, S-PV, DG, Ae, Fc, BES and load	200	P_{WG} = 0.5 P.u at 0 < t <40 s 0.4 P.u at t > 40 s P_{S-PV} = 0.2 P.u at 0< t <40 s 0.1 P.u at t > 40 s P_L = 1 P.u at 0 < t < 80 s 1.3 P.u at t > 80 s

Table.1: Case Studies under Simulation

V. RESULTS AND DISCUSSIONS

In this module, dynamic performance of the proposed hybrid model is analyzed for simulations in time domain. By defining various operating points and disturbance conditions are presented with optimum gain settings of conventional, GA and PSO based PI controllers respectively. The conventional optimization approach we considered here is ISE criterion where only one parameter is varied at a time keeping rest all parameters the same, for one complete iteration .we have considered the following two cases, as shown in table 1 are considered for case studies.

5.1 Time Domain Analysis under Case I

In this case study, we consider the below conditions for wind, solar and load analysis, during $0 \leq t \leq 40s$, the average wind power and solar irradiation power is kept 0.5PU and 0.36PU respectively after 40s, wind and solar power are suddenly reduced down to 0.36PU and 0.18PU respectively. Load demand during $0 \leq t \leq 80s$ is maintained at 1PU, after 80s the load demand suddenly elevates to 1.1PU. The deviation in the load demand to the generation is attuned by the Fuel cell, diesel, BES through controllers since generation from solar and wind is constant. Total power generated can be expressed by

$$P_S = P_{WG} + P_{STS} - P_{Ae} + P_{Fc} + P_{DG} + P_{BES}$$

Due to the sudden variations in the load demand, and variations in power outputs of solar and wind systems, there is a fluctuation in the system frequency at power level. This deviation in the power frequency is controlled by the controllers (PI) adjusting the system outputs automatically such that the error in the frequency deviation is minimized.
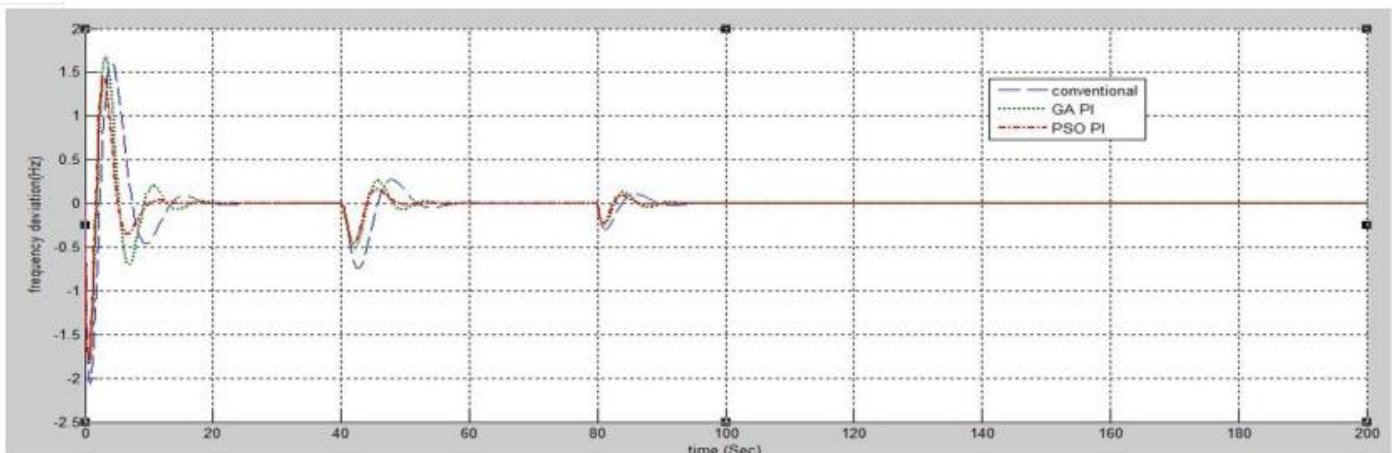

Fig.3. Comparative responses of Frequency deviations of PSO and GA based PI Controllers under Case I

5.2 Time Domain Analysis under Case II

In this case study, we consider the below conditions for wind, solar and load analysis, during $0 \leq t \leq 40s$, the average wind power and solar irradiation power is kept 0.5PU and 0.36PU respectively after 40s, wind and solar power are suddenly reduced down to 0.36PU and 0.18PU respectively. Load demand during $0 \leq t \leq 80s$ is maintained at 1PU, after 80s the load demand suddenly elevates to 1.1PU. The deviation in the load demand to the generation is attuned by the Fuel cell, diesel, BES through controllers since generation from solar and wind is constant. Total power generated can be expressed by

$$P_S = P_{WG} + P_{STS} - P_{Ae} + P_{Fc} + P_{DG} + P_{BES}$$

Due to the sudden variations in the load demand, and variations in power outputs of solar and wind systems, there is a fluctuation in the system frequency at power level. This deviation in the power frequency is controlled by the controllers (PI) adjusting the system outputs automatically such that the error in the frequency deviation is minimized.
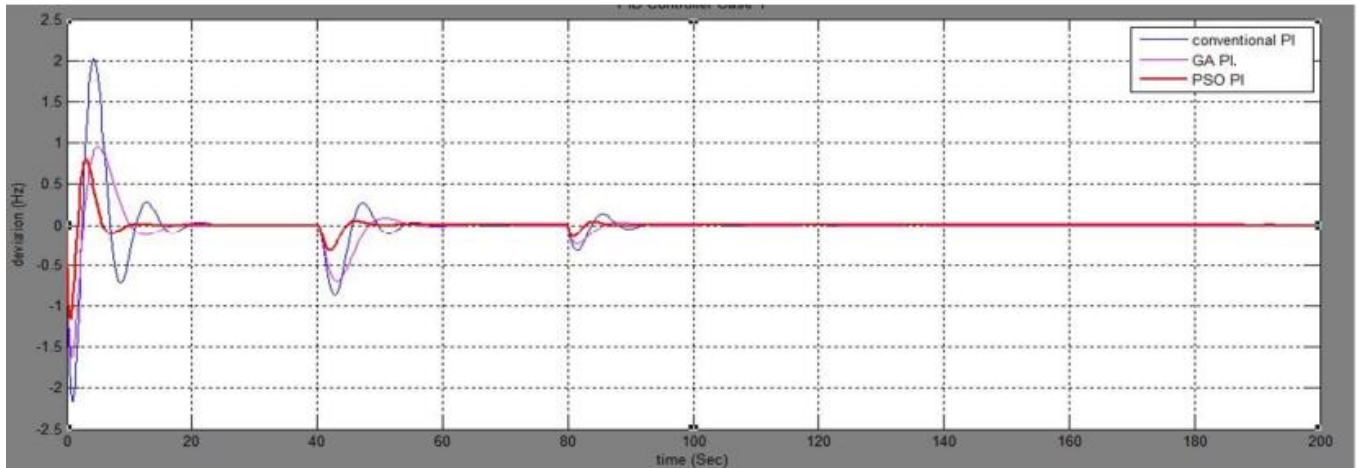

Fig.4. Comparative responses of Frequency deviations of PSO and GA based PI Controllers under Case II

VI. CONCLUSIONS

In this paper, PSO optimization algorithm based load frequency control of hybrid power system with renewable energy sources has been considered.In the first and second cases of the hybrid system consists of a solar thermal system and a solar PV system respectively, the superiority of the controller design approach has been shown by comparing results with conventional and GA based controllers. It is observed from simulation that PSO optimized PI controller performed better than the conventional and GA based controllers. The system performance indexes such as ISE and settling times reveal that the proposed approach proves its effectiveness more than others. Finally, the robustness analysis is carried out to test the robustness of the proposed PI controller for the above hybrid power system.

Investigations clearly reveal that the proposed PSO optimized PI controller parameters need not be reset even if the system is subjected to wide variation in loading condition and system parameters. It can be concluded, that PSO can be employed to maintain the system grid frequency to nominal range through AGC control.

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