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Optimal Design of Controller for Hybrid Power System using Soft Computing Technique

Vemireddi Tejeswara Rao¹, Umme Salma²

^{1,2}EEE Department, GITAM Institute of Technology, GITAM Deemed University, Visakhapatnam

Abstract: In this paper a controller is designed for a hybrid power system using a soft computing technique, the power system consists of PV system, fuel cell, aqua electrolyzer, diesel engine generator and a battery energy storage system and frequency of the system is controlled by proportional plus integral (PI) controller and proportional plus integral and derivative (PID) controller. A powerful optimization technique named as particle swarm optimization technique is used for optimization of controller gains of the proposed hybrid power system. The system responses with particle swarm optimization-based controllers are compared with the classical method.

Keywords: Particle swarm optimization, hybrid power system, fuel cell, aqua electrolyzer, battery energy storage system, diesel engine generator.

Nomenclature

Δf	-	Deviation in system frequency
P_s	-	system total power generation
P_L	-	absorbed power in average by load
ΔP_e	-	error in supply to power demand
M	-	inertia constant of Hybrid model power system
D	-	damping constant of Hybrid model power system
P_{DEG}	-	power output of diesel generator
G_{DEG}	-	first order transfer function of the diesel engine generator
K_{DEG}	-	Gain of diesel engine generator
T_{DEG}	-	time constant of diesel engine generator
P_{PV}	-	power output of solar photovoltaic system
G_{PV}	-	first order transfer function of the solar photovoltaic system
K_{PV}	-	Gain of solar photovoltaic system
T_{PV}	-	time constant of solar photovoltaic system
P_{Fc}	-	power output of the fuel cell
G_{Fc}	-	first order transfer function of the fuel cell
K_{Fc}	-	Gain of Fuel cell generator
T_{Fc}	-	time constant of Fuel cell
P_{BES}	-	power output of battery energy storage system
G_{BES}	-	first order transfer function of the battery energy storage system
K_{BES}	-	Gain of battery energy storage system
T_{BES}	-	time constant of battery energy storage system
P_{AE}	-	power output of aqua electrolyzer unit
G_{AE}	-	first order transfer function of the aqua electrolyzer
K_{AE}	-	Gain of aqua electrolyzer unit
T_{AE}	-	time constant of aqua electrolyzer unit

I. INTRODUCTION

In the recent times, the power needs are increasing day by day. To meet the demand, new ways of power generating techniques to be investigated. Photovoltaic systems are being supported by many governments on a worldwide basis. Discontinuity which is caused due to the energy produced by solar panels wind energy necessitates the use of some control. On the other hand, auxiliary systems can be used to minimize cost and maximize reliability. The best auxiliary system is that which produces the least emission and has the least cost.

For this purpose diesel turbine is used in this project. Due to the high price of solar panels, in order to reduce the cost and of course increase the reliability, utilizing an auxiliary system is recommended. Wind and solar energy, as the most abundant renewable energy sources, have experienced the greatest development during the last few years. Today, their technology is becoming feasible and economic. Often these resources are widely available, or perhaps even the only available energy sources in some remote areas. Often they are not integrated with a grid.

The electricity generation is variable in time because the operation of a wind or solar based system highly depends on weather conditions and as result the pattern does not actually follow the load demand. Energy needs to be stored in order to fulfill the energy requirements during a period of low available resources.

Batteries are the most popular way to store energy, but they lose their energy content rapidly and therefore they can be only used over a short time period. Batteries also have a limited life cycle and problems with depth of discharge, often requiring replacement of service. So due to this concern we also used fuel cells for energy storage device. Fuel cells are devices that produce electricity as long as they are supplied with a fuel.

They rely on direct electrochemical conversion of a fuel and therefore they are much more efficient than internal combustion devices, reaching operational efficiencies of 40%.

The design of the controllers includes both conventional and computational intelligence techniques. Numerous optimization methodologies, such as differential evolution, genetic algorithm, particle swarm optimization, artificial neural network, bat algorithm, are applied to optimize and calculate the gains of the controllers for automatic generation control. The above stated methods were limited to conventional systems but never applied for hybrid systems for optimization of gains for the controllers. 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 controller's does not meet the required robust performance which is certainly not desired.

In this paper, the PSO PI, PID controllers used whose gain values are calculated using PSO technique. The PSO is a novel technique which has widespread applications in the system optimizations. The intelligent control strategy provides robust adaptive response with varying parameters like non-linearity, load disturbances. The basics of PSO algorithm are illustrated. By applying PSO PI, PID controllers to the hybrid system the results obtained are compared with conventional PI, PID controllers respectively. Simulated results show that gains obtained from PSO has improved dynamic performance than the conventional controllers.

II. MODELING OF THE SYSTEM

The various renewable sources are integrated for an effective and reliable power supply during different load conditions. These sources like wind and PV have random characteristics due to different climatic conditions. Both wind speed and solar radiations have complimentary features which may reduce the capacity of the energy storage system. Hence fuel cell may be integrated with such sources along with the energy storage system such as battery energy storage system.

The proposed system consists of a photo voltaic system, diesel generator, fuel cell, aqua electrolyzer, and battery storage system. The output power of PV is linearly varied with solar radiation if ambient temperature value keeps constant. The power supplied to the load is the sum of output powers from photo voltaic system, diesel generator, fuel cell and battery energy storage system. The aqua electrolyzer is used to absorb the fluctuations of solar radiation and produce the hydrogen gas which is used as input to fuel cell generator. The proposed system simulation model is shown in figure1. The mathematical models with first order transfer functions for photo voltaic system, fuel cell, aqua electrolyzer, diesel engine generator are shown in this section.

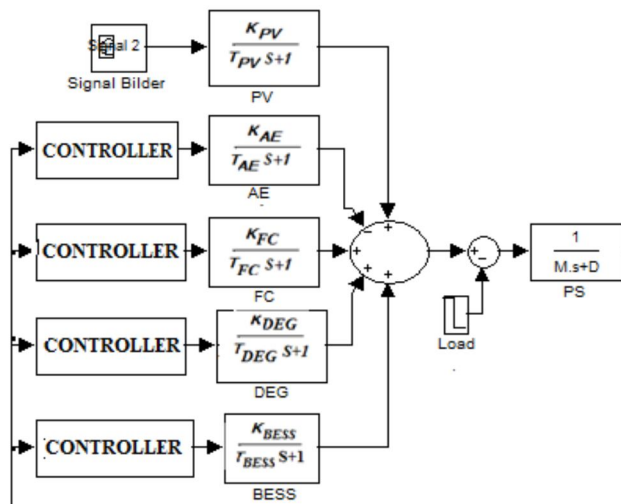


Fig: Proposed hybrid power system model

A. Characteristics of PV Output Power

The sun is an abundant and readily available source of energy. A photo voltaic system captures the sun's energy and Converts it into usable electricity. The output power of studied PV system is determined by

$$P = \eta S \Phi \{1 - 0.005(T_a + 25)\} \text{ (KW)}$$

Where η is the conversion efficiency of PV array, S is the measured area of PV array (m^2), Φ is the solar radiation (kW/m^2), and T_a is the ambient temperature. Generating power of PV system depends on ambient temperature and Solar radiation because conversion efficiency of PV array and area of PV array are constant. in this paper assuming ambient temperature is constant and output power of PV array varied by solar radiation only.

The transfer function model of PV represented by a first order lag as

$$G_{PV}(s) = \frac{K_{PV}}{1 + sT_{PV}}$$

Where, T_{PV} , G_{PV} are the time constant and gain of photo voltaic system. The values of T_{PV} and K_{PV} are 1.8 s and 1.0 respectively.

B. Aqua Electrolyzer

It is a device used to produce the hydrogen. The decomposition of water into hydrogen and oxygen can be achieved by passing the electric current between the two electrodes separated by aqueous electrolyte. Part of generated energy from the photovoltaic system is send to the aqua electrolyzer to produce hydrogen for fuel cell.

The transfer function model of aqua electrolyzer is given by

$$G_{AE}(s) = \frac{K_{AE}}{1 + sT_{AE}}$$

Where K_{AE} and T_{AE} represent the gain and time constant of AE. The value of T_{AE} is very small because AE consists of several power converters. The values of K_{AE} and T_{AE} are 0.002 and 0.5s respectively.

C. Fuel Cell

Fuel cells are not only very efficient but also have very low emission levels. Fuel cell power generation systems provide a clean alternative to the conventional fossil fuel based systems. FC is an electrochemical device that continuously converts the chemical energy of a fuel and oxidant into electrical energy and heat as long as the fuel and oxidant are supplied to the electrodes. Fuel cell generators are of higher order models and have non linearity. However in low frequency domain analysis it is represented by a first order lag transfer function model given as

$$G_{FC}(s) = \frac{K_{FC}}{1 + sT_{FC}}$$

Where K_{FC} and T_{FC} represent the gain and time constant of fuel cell. The values of K_{FC} and T_{FC} are 0.01 and 4s respectively.

D. Diesel Engine Generator

Standby diesel engine generator (DEG) work autonomously to supply the deficit power to the hybrid systems to meet the supply-load demand balance condition depending upon the wind power generation as well as load demand. The transfer function of DEG can be given by a simple linear first-order lag

$$G_{DEG}(s) = \frac{K_{DEG}}{1 + sT_{DEG}}$$

Where K_{DEG} is the gain and T_{DEG} is the time constant of the diesel engine generator. The values of K_{DEG} and T_{DEG} are 1/300 and 2s respectively.

E. Battery Energy Storage System

Batteries are considered a major cost factor in small-scale standalone power system. The usage of battery energy storage systems (BESS) has created a greater focus on the reduction of adverse effects of the frequency deviations. By installing BESSs to a power system with WTGs, the power fluctuations can be reduced and also the power system stabilities can be ensured to overcome the fluctuation. Since integrating large batteries with WTGs increase the cost of the power system, it is economically beneficial to utilize small batteries for the output power control of the integrated system. BESS can supply the system with a large amount of the power in a short time. The transfer function model of battery energy storage system (BESS) is expressed by first order

$$G_{BESS} = \frac{K_{BESS}}{1 + sT_{BESS}}$$

Where K_{BESS} and T_{BESS} represent the gain and time constant of battery energy storage system. The values of K_{BESS} and T_{BESS} are 1/300 and 0.1s.

F. Power and Frequency Deviation

In a power system, the output frequency depends on the generation and load. If generation or load changes then automatically power system frequency deviates. To achieve stable operation the error in frequency should be minimum. The deviation in power is the difference between net output powers to the total load demand

$$\Delta P_e = P_s - P_L$$

Since there exists a time delay between system frequency variation and power deviation, the transfer function for system frequency variation to per unit power deviation is given by

$$\Delta f = \frac{1}{Ms + D}$$

Where M and D are, equivalent inertia constant and damping constant of power system respectively, and K is the system frequency characteristic constant. The values of M and D are 0.012 and 0.2 respectively.

III. OBJECTIVE FUNCTION

A measure of system performance formed by integrating the square of the system error over a fixed interval of time. ISE will penalize large errors more than smaller one's (since the square of a large error will be much bigger). Control systems specified to minimize ISE will tend to eliminate large errors quickly, but will tolerate small errors persisting for a long period of time. Often this leads to fast response, but considerably, low amplitude, oscillation.

$$ISE = \int (\Delta f)^2 dt$$

If response shows large deviation from set point, ISE criteria should be used because squaring of the deviation term contributes more to cost (objective function) which eventually drags the optimization algorithm towards a set of controller parameters that ensures minimization of the cost.

IV. PARTICLE SWARM OPTIMIZATION TECHNIQUE

Particle swarm optimization (PSO) is a population based stochastic optimization technique developed by Dr. Eberhart and Dr. Kennedy in 1995, inspired by social behavior of bird flocking or fish schooling. In PSO, the potential solutions, called particles, fly through the problem space by following the current optimum particles. PSO simulates the behaviors of bird flocking. Suppose the following scenario: a group of birds are randomly searching food in an area. There is only one piece of food in the area being searched. All the birds do not know where the food is. But they know how far the food is in each iteration. So, what's the best strategy to find the food? The effective one is to follow the bird which is nearest to the food. PSO is initialized with a group of

random particles (solutions) and then searches for optima by updating generations. In every iteration, each particle is updated by following two "best" values. The first one is 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 population. This best value is a global best and called Gbest. When a particle takes part of the population as its topological neighbors, the best value is a local best and is called lbest.

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 represent 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 mat lab 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 P_{best} and G_{best} 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

In PID controller design method, the most common objective functions 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.

$$J = \int_0^{\infty} (\Delta f)^2 dt$$

Minimize J

Subjected to

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

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

$$K_d^{\min} < K_d < K_d^{\max}$$

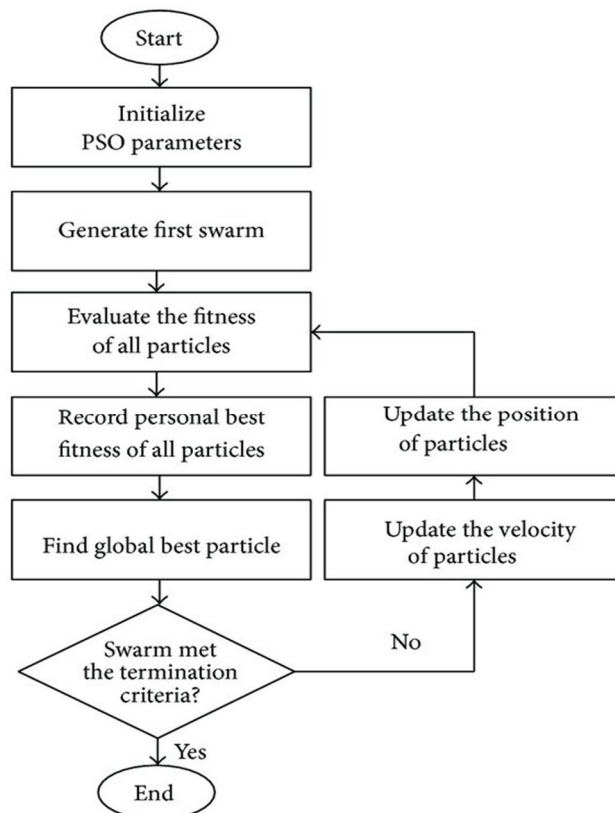


Fig: Flow chart for Particle Swarm optimization algorithm

V. RESULTS

In this section we presented the time domain performance of the proposed hybrid power system. Simulation interval is taken as 300s. For any change in generation and load the power system frequency deviates this deviation is controlled using the proportional plus integral (PI) controller and proportional plus integral derivative (PID) controller. The controller gains are tuned by Particle swarm optimization technique. The changes in generation and load are automatically adjusted by Generating sources.

A. Case I

Using proportional plus integral (PI) controller

- 1) *Increase in load from 1 to 1.3 Pu:* In this case PI controllers are installed before the DEG, AE, FC and BESS. Solar radiation is kept 0.5 pu up to 300s and load demand is 1 pu. Up to 150s and after 150s load is suddenly increases from 1 to 1.3 pu. The power system frequency fluctuates due to changes in load, if load increases then frequency decreases to corresponding value. This deviation in frequency is controlled by the PI controllers and the outputs of Generators are automatically adjusted to corresponding values such that the error in supply demand and the deviation in frequency are minimum. The gain values of PI controllers which are installed before AE, FC, DEG and BESS obtained through Particle Swarm Optimization technique and classical method are $K_{p1}=1.1774$, $K_{i1}=0.3747$, $K_{p2}=3.1367$, $K_{i2}=3.4266$, $K_{p3}=6.2386$, $K_{i3}=0.2432$, $K_{p4}=65.8191$, $K_{i4}=5.3567$, $K_{p1*}=3.675$, $K_{i1*}=4.52$, $K_{p2*}=6.588$, $K_{i2*}=9.427$, $K_{p3*}=5.845$, $K_{i3*}=5.598$, $K_{p4*}=3.02$, $K_{i4*}=4.487$ the deviation in frequency is shown in the below figure

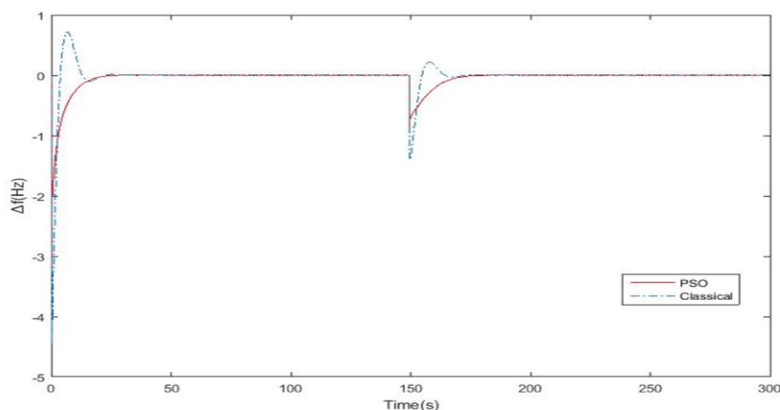


Fig: Deviation in frequency in the system with the PI controller, when the load suddenly increases

- 2) *Load Decreases from 1 to 0.7 pu:* In this case PI controllers are installed before the DEG, AE, FC and BESS. Solar radiation is kept 0.5 pu up to 300s and load demand is 1 pu. Up to 150s and after 150s load is suddenly decreases from 1 to 0.7 pu. The power system frequency fluctuates due to changes in load, if load decreases then frequency increases to corresponding value. This deviation in frequency is controlled by the PI controllers and the outputs of Generators are automatically adjusted to corresponding values such that the error in supply demand and the deviation in frequency are minimum the deviation in frequency is shown in the below figure

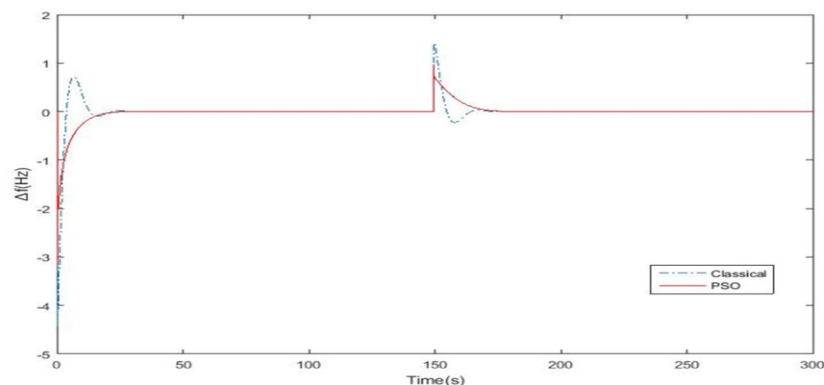


Fig: Deviation in frequency in the system with the PI controller, when the load suddenly decreases

B. Case II

Using PID controller

- 1) *Load Increases From 1 To 1.3 PU:* In this case PID controllers are installed before the DEG, AE, FC and BESS. Solar radiation is kept 0.5 pu up to 300s and load demand is 1 pu Up to 150s and after 150s load is suddenly increases from 1 to 1.3 pu. The power system frequency fluctuates due to changes in load, if load increases then frequency decreases to corresponding value. This deviation in frequency is controlled by the PID controllers and the outputs of Generators are automatically adjusted to corresponding values such that the error in supply demand and the deviation in frequency are minimum. The gain values of PID controllers which are installed before AE, FC, DEG and BESS obtained through PSO technique and classical method are $K_{p1}=3.2719$, $K_{i1}=0.7099$, $K_{d1}=0.0292$, $K_{p2}=0.7282$, $K_{i2}=3.1714$, $K_{d2}=3.1714$, $K_{p3}=1.6184$, $K_{i3}=-2.3138$, $K_{d3}=0.5963$, $K_{p4}=5.2412$, $K_{i4}=1.3869$, $K_{d4}=3.4674$, $K_{p1*}=1.7613$, $K_{i1*}=0.7178$, $K_{d1*}=8.935$, $K_{p2*}=7.44$, $K_{i2*}=5.668$, $K_{d2*}=6.852$, $K_{p3*}=8.138$, $K_{i3*}=4.278$, $K_{d3*}=4.9673$, $K_{p4*}=4.668$, $K_{i4*}=6.658$, $K_{d4*}=2.985$. the deviation in frequency are shown in the below figure

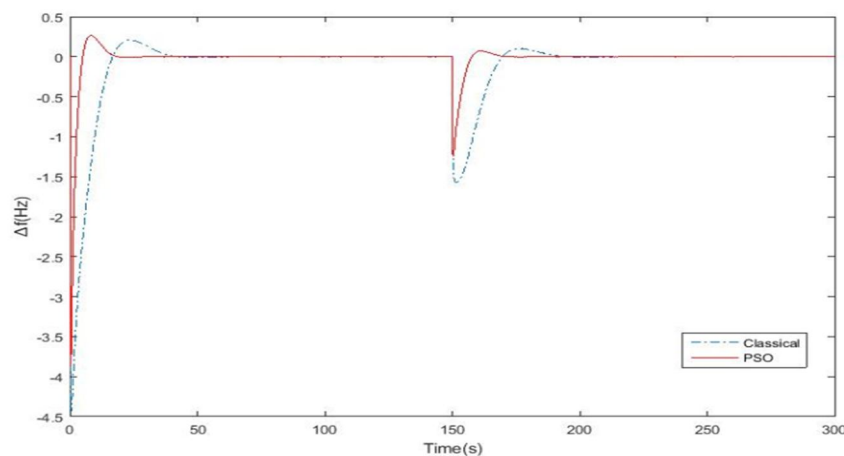


Fig: Deviation in frequency in the system with the PID controller, when the load suddenly increases

- 2) *Load Decreases From 1 To 0.7 PU:* In this case PI controllers are installed before the DEG, AE, FC and BESS. Solar radiation is kept 0.5 pu up to 300s and load demand is 1 pu. Up to 150s and after 150s load is suddenly decreases from 1 to 0.7 pu. The power system frequency fluctuates due to changes in load, if load decreases then frequency increases to corresponding value. This deviation in frequency is controlled by the PI controllers and the outputs of Generators are automatically adjusted to corresponding values such that the error in supply demand and the deviation in frequency are minimum the deviation in frequency is shown in the below figure

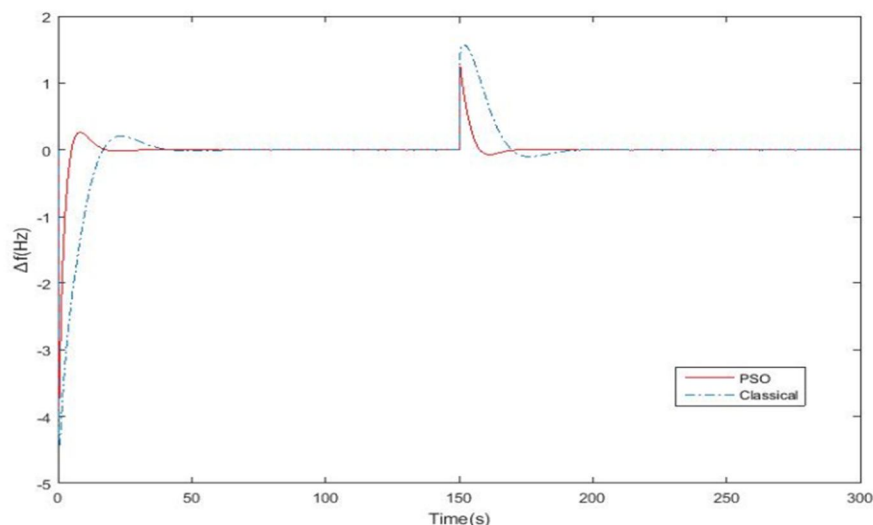


Fig: Deviation in frequency in the system with the PID controller, when the load suddenly decreases

VI. CONCLUSION

In this paper, the gains of each controller installed before the FC, AE, DEG and BESS are designed by Particle swarm optimization technique and classical method. The results are compared and from the results it is observed that Particle swarm optimization technique is much better compared to the classical method and PID controller gives better results than the PI controllers

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