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Particle Swarm Optimization and Gradient Descent Methods for Optimization of PI Controller for AGC of Multi-area Thermal-Wind-Hydro Power Plants

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Abstract— **The automatic generation control (AGC) of three unequal interconnected Thermal, Wind and Hydro power plant has been designed with PI controller. Further computational intelligent technique Particle Swarm Optimization and conventional Gradient Descent technique have been used to improve the performance of Automatic Generation Control (AGC) system. The reheat turbine for thermal area and appropriate generation rate constraint (GRC) have been considered for thermal area. Particle swarm optimization (PSO) technique and Gradient Descent methods are used to simultaneously optimize the proportional gain (Kp), integral gains (Ki), speed regulation parameter (Ri) and frequency bias (Bi) parameter of different areas. Most of the literature for AGC used classical approach based on integral squared error (ISE) technique etc. for optimal selection of controller parameters. This is a trial and error method; extremely time consuming when several parameters have to be optimized simultaneously. The computational intelligence based technique like PSO is more efficient and fast technique for optimization of different gains in load frequency control. Further the performance of PSO is better than GD method for optimization of various parameters and the controller gives the improved dynamic performance for three area network with Thermal–Wind-Hydro power plants.MATLAB/SIMULINK is used as a simulation tool.**

Keywords- *Automatic generation control; Particle swarm optimization; Gradient Descent method; Generation rate constraint; Area control error; Wind energy conversion system*

I. INTRODUCTION

The main task of an electrical power system is to maintain the desired operating level of frequency, voltage profile and load flow conditions. A balance between power demand and power generation is required to provide users with reliable, high-quality electric power. The control of real and reactive powers generated is done by changing the parameters of controllable sources in the system. When the load changes the operating point of the power system may change very much during a duty cycle [2].The changes in the power demand affect the frequency of the power system as well as the tie-line power flow between control areas [6]. The main objective of the Load Frequency Control is to keep the system frequency at the scheduled value by regulating the generator units with area control error (ACE) and making the area control error tending to zero under the continuous adjustment of active power [3,4].

Traditionally, the area control error (ACE), which is the combination of area frequency bias times frequency deviation and net power interchange error or net tie-line flow error is used as the input of the load frequency controller whose objective is to control the ACE and the interconnection frequency deviation. The load frequency controllers used in the industry are proportional-integral (PI) type and are tuned online based on trial-and-error approaches [7]. Several optimization techniques have been proposed to tune the control parameters using simulation of the entire system rather than just the control area being studied [4, 6]. Some of them simply assume that all subsystems are identical, which is not the case of actual power systems [11]. Subsequently, a number of decentralized load frequency controllers were developed to eliminate the above drawback.

The controller used here is a PI controller tuned by a robust control design algorithm called particle swarm optimization to achieve the robust performance details. One more method called Gradient Descent has also been applied to tune the different parameters. The proper selection of governor droop or governor speed regulation parameter (R in Hz/p.u. MW) is also very important for obtaining the zero steady state error in frequency. More over the suitable value of frequency bias setting (B) in governor supplementary control also help in AGC. Thus the optimization of Ri and Bi is also done with the proposed techniques along with the Kp and Ki.

In order to obtain the optimal controller parameters with regards to controller structure constraints, Particle Swarm Optimization (PSO) and Gradient Descent are powerful search techniques and are used to find the control parameters of the PI load frequency controller [10].

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II. MODELLING OF AGC FOR THREE -AREA THERMAL-WIND-HYDRO POWER SYSTEMS

The system considered in this work is consisting of three areas: thermal, hydro and wind power plants. The different areas are connected by a tie-line and the transfer function model using MATLAB simulink has been designed. The thermal system is designed considering the GRC and single reheat turbine. The thermal and hydro areas taken for investigation is of 2000MW each The suitable Generation Rate Constraint is taken into account and generally it is found to be 3%/min.[1,9,11].For the small deviations in speed, only normal speed regulation has been considered, the generic model shown in Fig. 1 can be used to show the turbine control function [17].

The other parameters of the thermal and hydro power systems are given in Table-II [2]. GRC for the subsystem is 0.0005 p.u. MW/sec. The wind power plant of nominal rating of 35 MW is also connected in the three area network and the transfer function model is developed for the wind power plant assuming a constant speed of wind [16].The second order dynamics of wind energy conversion system is given by choosing the proper natural frequency ω_n and damping factor ζ which further gives the controller parameters.

$$Ti = 2\zeta/\omega_n - 1/\omega_n^2 T_{pt}$$
$$K_p = (Ti\, T_{pt} / K_{pt})\, \omega_n^2$$

A high value of K_p ensure the better tracking performance but control effect limitation arises ,so the K_p must be limited .The increase in overshoot is compensated by first order filtering of the reference signal. The dynamic behavior of Wind Energy Conversion System (WECS) can be given by two- pole- one -zero transfer function as given below:

$$H_{pt}(s) = \frac{K_{pt}(T_z s + 1)}{(T_\Sigma s + 1)(T_{pt} s + 1)}$$

T_{pt} and T_Σ are main and parasitic time constant respectively. The closed loop structure of WECS with PI control is as shown in Fig 2.

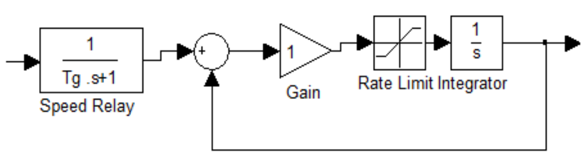

Figure 1. Generic speed governing system model

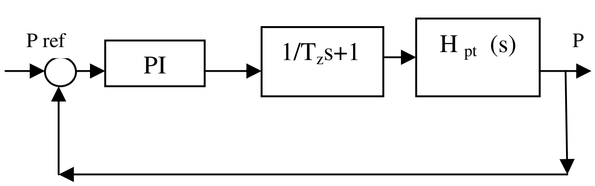

Figure 2. Wind Energy Conversion system

The wind farm parameters are given in Table-III Recently the active power control of the variable speed wind turbines is becoming more mature with the advanced power electronic technology. The inertial and speed-droop controls of wind turbines for frequency response are widely used. The developed control loop within the wind turbine is like the speed governor which automatically adjusts power output in response to a frequency drop. However, due to the wind variability, the speed-droop control has its own limitation. Because wind power is an intermittent motive source which differs from the source applying to the traditional plants, the control of wind turbine output is much more challenging[14].An appropriate coordination between stability and controllability of active power in wind turbines should be maintained.

The equation of objective function (ISE) used is given below:

$$ISE = \int \{(\Delta f_i)^2 + (\Delta Ptie_{i-j})^2\} dt$$

A step load perturbation of 1% of nominal loading has been considered in one area at a time .The effect on frequency is observed on all the areas. The gains along with B and R of all the three areas are optimized using PSO and GD technique to have the minimum frequency deviation.

The comparison is done between the performance of PSO and GD method for frequency control of three areas thermal, hydro and wind power system. The various notations used in plots of system responses are as given:

delf1= change in frequency of Area -1
delf2= change in frequency of Area -2
delf3= change in frequency of Area -3
gdt =GD tuned
psot =PSO tuned

III. RESULT AND DISCUSSION

The three unequal area system with thermal, wind and hydro power plants as described in section II is considered for studies. The dynamic responses have been obtained with 1% load change in one area at a time, which is affecting the frequency of other systems also. For the automatic generation control the PSO and GD methods have been applied for optimizing the values of Kp, Ki ,Ri and Bi of various areas. The analysis and comparison of PSO and GD method has been done .

The objective function (ISE) of system shown in Fig 3 is given to the PSO technique .The population size taken is 50 and maximum number of iterations is limited to 100.The values assigned to c_1, c_2 are 2 each and w_{max}=0.9,w_{min}=0.4 The twelve variables obtained after optimizing the PI controller ,frequency bias and speed regulation parameter of each area simultaneously are provided in Table I.

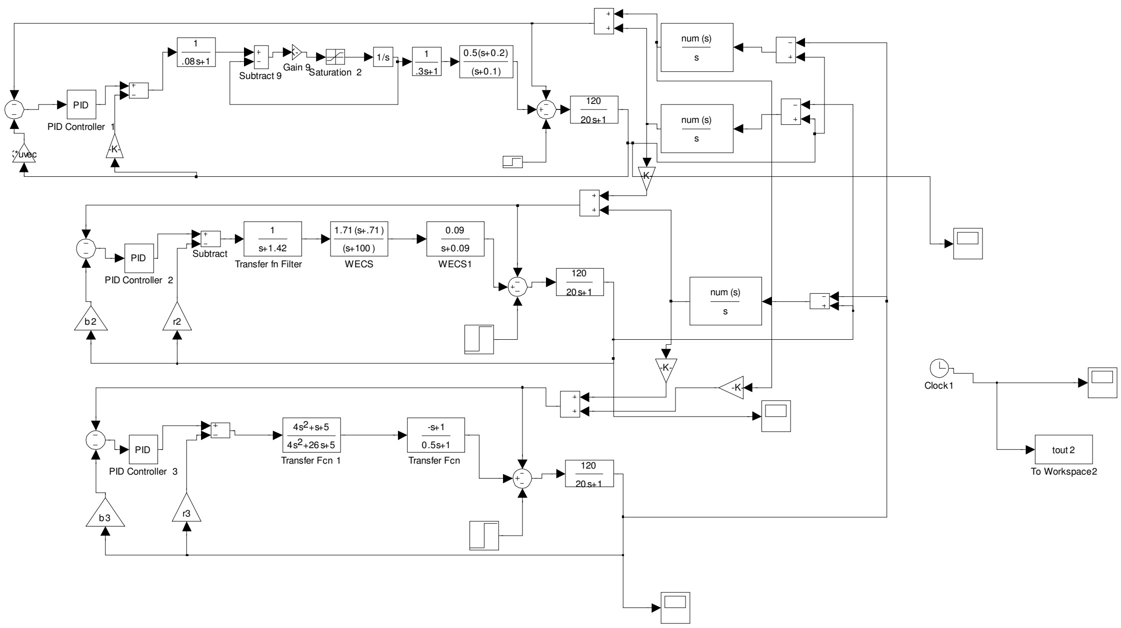

Figure 3. Transfer function model in MATLAB for three area interconnected reheat thermal ,wind and hydro power system

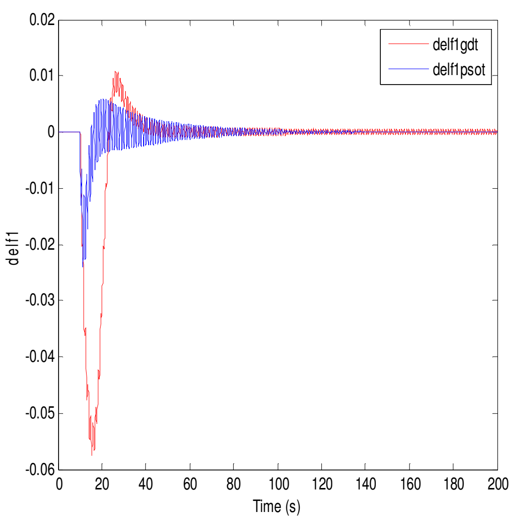

Figure 4. Frequency response of area-1 for 1% change in load of area-1

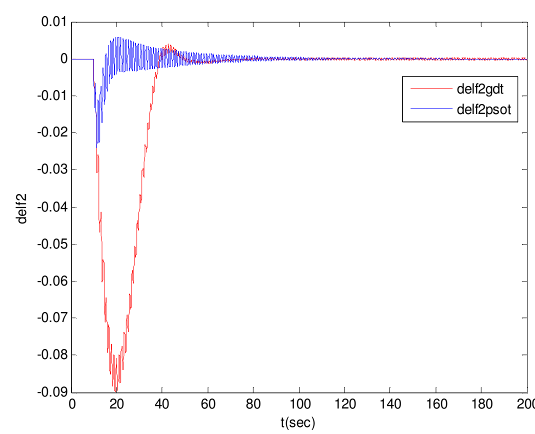

Figure 5. Frequency response of area-2 for 1% change in load of area-1

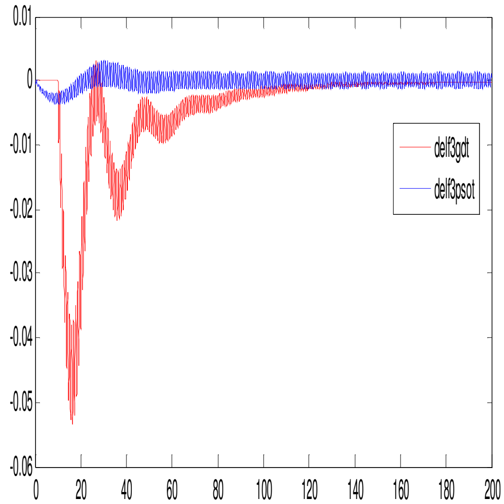

Figure 6. Frequency response of area-3 for 1% change in load of area-1

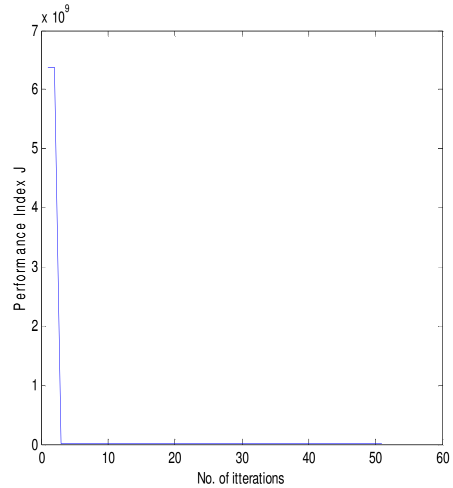

Figure 8. Performance Index using PSO technique

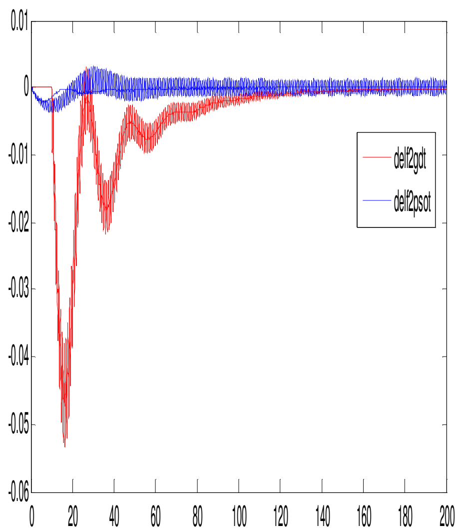

Figure 7. Frequency response of area-2 for 1% change in load of area-2

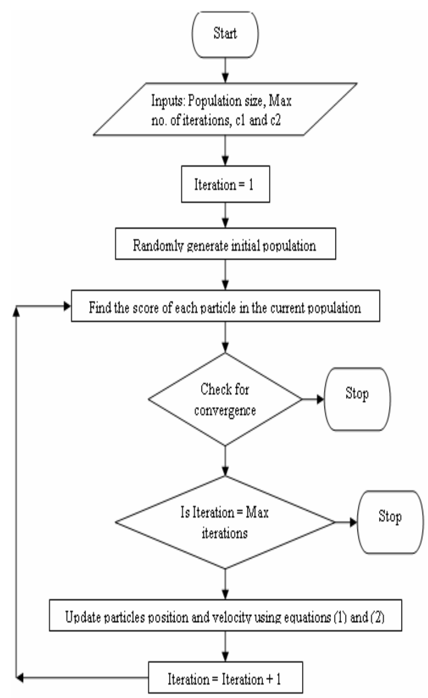

Figure 9. Flowchart of Particle Swarm Optimization

The dynamic responses have been shown in Fig 4-Fig 7. The performance index variation using PSO method has been shown in Fig 8.For applying the GD technique the frequency response is applied to signal constraint block in MATLAB SIMULINK. The reference signal has been given in signal constraint block to get the desired response. The initial values assigned to all twelve parameters added in tuned parameters are zero. The time vector range is selected as [0 500].For the desired response the initial and final amplitude are assigned the value as [0 0].The variables to be optimized have been added to tuned parameters block of signal constraint. The results obtained by GD method are given in Table I.

TABLE I. OPTIMIZED VALUES OF SYSTEM VARIABLES USING PSO AND GD TECHNIQUES

Interconnected Areas	Optimum Parameters	Controller and System parameters optimized by PSO	Controller and System parameters optimized by GD
Thermal Power System	Kp1	0.0100	-0.0839
	Ki1	0.2000	0.0358
	B1	0.0900	-0.1322
	R1	0.0100	0.0631
Wind Energy Conversion System	Kp2	0.1358	-0.3656
	Ki2	0.2000	0.1467
	B2	0.0143	0.0219
	R2	0.0100	0.1244
Hydro Power Plant	Kp3	0.0100	-0.0921
	Ki3	0.1319	0.00015
	B3	0.0100	-0.0261
	R3	0.0100	0.1452

The dynamic responses have been shown in Fig4 – Fig 7.The frequency deviation is less in case of PSO method as compared to frequency deviation in GD method for the same load change in specific area. The settling time is almost same in both the methods .These responses indicate that PSO is a better method for automatic generation control than GD method.

IV. OVERVIEW OF PARTICLE SWARM OPTIMIZATION (PSO)

PSO is a population-based optimization method first proposed by Eberhart and Colleagues. Some of the attractive features of PSO include the ease of implementation and the fact that no gradient information is required. It can be used to solve a wide array of different optimization problems. Particle swarm optimization (PSO) is a stochastic optimization technique based on a collection of population (swarm) and inspired by social behavior of the movement of bird or fish to find food sources.

To find the optimal solution, every bird, or in this case the particle, set the search direction based on two factor, namely previous best experience (pbest) and the best experience of all the birds that exist in this population (gbest). PSO model consists of a set of particles initialized with a population of candidate solutions at random [10]. The flowchart for PSO has been shown in Fig 9. Particles moving through space with a d-dimensional problem to seek new solutions, with fitness f, can be calculated as a determined measuring quality. Each particle has a position represented by the vector-position xi (i is the index of the particle) and speed (velocity) is represented by the vector velocity vi. Each particle has so far resulted in the best position (pbest) in vector xik, and the value of the j-th dimension is xijk. Vector best position among the compounds (swarm) so far (gbest) is stored in a vector xl, and the value of the j-th dimension is xjl. During this time of iteration (t), the particles update the speed of the previous speed with the new speed determined. The new position is determined by the sum of the previous position and the new velocity.

V. CONCLUSION

An attempt has been made to simultaneously optimize the PI controller and system parameters of three interconnected Thermal-Wind-Hydro power plants, using computational intelligent technique PSO and conventional GD technique for load frequency control .The frequency change occurs in all the three areas due to load fluctuation in one area at a time. The transfer function model for the wind power plant has been developed assuming a constant wind speed. The interconnection of wind power plant with thermal and hydro power plant has been done, and then the frequency control is done with PI control for this interconnected system. The simulation studies using MATLAB have been done which show that the PI controller is effective for controlling the frequency change along with suitable frequency bias feedback gain (Bi) and governor speed regulation parameter (Ri). The PSO technique used for optimization of proportional gain (Kp), integral gain (Ki), speed regulation parameter (Ri) and frequency bias (Bi) parameter of different areas is very efficient and powerful computational intelligent technique in comparison to conventional Gradient Descent technique.

TABLE II. NOMINAL PARAMETERS OF THERMAL AND HYDRO SYSTEMS SIMULATED

f=60 Hz	Kr= 0.5
Tg= 0.08 s	Tt = 0.3sec
Ptie max=200 MW	Kp=120 Hz/puMW
Tr=10s, T12=0.544	Tp=20 s
H=5 sec	Pr=2000MW
D=0.00833 p.u.MW/Hz	R=2.4Hz/p.u.MW

TABLE III. NOMINAL PARAMETERS OF WIND POWER PLANT SIMULATED

Density of air = 1.25 kg/m3 Gear ratio =70	T_{pt} = 10.55
Radius of turbine blade= 45 m	K_{pt} = 0.012
Average wind velocity= 7 m/s	Ti = 3s
H=5 sec	Tp=20 s

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