A critical comparative observation on Automatic Generation Control of Thermal Power-CSP system using Firefly Algorithm based classical control

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Abstract- For all intents and purposes all power system is of multi-area in nature. Consequently investigation of multi-area power system is critical. Essential issues of multi-area power system are Automatic Generation Control (AGC) which controls the system frequency and Automatic Voltage Regulator (AVR) that keeps system voltage steady at evaluated esteem. This paper displays comparative study of an Automatic Generation Control plan for multi area power systems utilizing integrator, PID controller and optimization technique namely firefly algorithms (FA). For multi area simulation result are compared in MATLAB/SIMULINK. Automatic Generation Control (AGC) is a vital procedure that works continually to adjust the generation and load. PID controllers can be tuned by utilizing numerous techniques. In all strategies an underlying conjecture is made for PID controller parameter settings. At that point these parameter settings are enhanced by adjusting of the controller. Presently a day's different simulation programming is generally utilized for this motivation behind parameter settings. Also the working of the controllers is simulated using MATLAB/SIMULINK for tuning of PID controller. To begin with this strategy is exhibited in point of interest for Automatic Voltage Regulator (AVR) of an isolated power system.

Keywords –Automatic Generation Control (AGC), Automatic Voltage Regulator (AVR), Load Frequency Control (LFC), Economic Dispatch (ED), Concentrating Solar Power (CSP), Firefly Algorithm (FA).

I. INTRODUCTION

The main target of automatic **generation control (AGC)** is a power-driven system for changing the electrical energy output of numerous generators at various generating plants, because of changes in the variation of demand. Since a grid power requires that load and generation power nearly adjust minute by minute, successive changes in accordance with the yield of generators are essential. The balance can be judged by measuring the system frequency; in the event that it is expanding, more power is being created than utilized, and every one of the machines in the system are quickening. On the off chance that the system recurrence is diminishing, a greater number of burdens is on the system than the immediate generation can give, and all generators are back down.

Prior to the utilization of AGC, one producing unit in a system would be assigned as the managing unit and would be physically acclimated to control the harmony in the middle of generation and load to keep up frequency of the system recurrence at the sought worth. The remaining units would be controlled with velocity hang to share the load in extent to their evaluations. With programmed system, numerous units in a system can take an interest in regulation, decreasing wear on a solitary unit's controls and enhancing general system productivity, stability, and economy.

Where the network has attach interconnections to adjoining control territories, AGC keeps up the power exchanges over the tie lines at the planned levels. With PC based control systems and various inputs, an AGC system can consider such matters as the most efficient units to conform, the coordination of hydroelectric, thermal and other generation sorts, and even limitations identified with the soundness of the system and limit of interconnections to other power matrices.

The objective of the AGC in an interconnected power system is to maintain the frequency of each area and to keep tie-line power close to the scheduled values by adjusting the MW outputs the AGC generators so as to accommodate fluctuating load demands.

The components of AGC in the modern power system are:

- Load-frequency control (LFC)
- Economic dispatch (ED)
- Interchange scheduling (IS)

When frequency changes, under primary regulation, governors respond immediately. In any case, as specified prior, frequency does not get restored but rather will settle down at an alternate quality. As of right now of time LFC capacity comes into the photo. LFC maintains the system frequency by performing the function of Secondary Regulation. It gives generation set focuses to the generators taking an interest in the frequency regulation. Yet, these set focuses may not be the ideal from cost perspective. Economic dispatch (ED) capacity straightens out the set purposes of the eras after the time size of LFC. In a substantial interconnected power system there are various territories associated by tie lines with offer concurrences with neighbors. The ED and LFC terms needs to tend of these activities. This capacity is performed by Interchange Scheduling (IS). Each of these areas is responsible for generating enough power to meet its own customers or "native load." By keeping the produced power equivalent to the power devoured by load, utilities keep the general frequency of systems at 50 Hz. Not just should zones conform their generation to meet their own particular changing local load, yet they should likewise keep up any booked tie-line exchanges. It is conceivable, by checking both the tie-line flow and the frequency of system to decide the best possible generation activity (raise or lower). Thus, electric utilities use an automatic generation control (AGC) system to balance their moment-to-moment electrical generation to load within a given control area.

II. LITERATURE REVIEW

In an interconnected electrical power system, effective, monetary and dependable operation of the system requires frequency of system and attaches line power trade to be kept up altered to their ostensible qualities. Automatic generation control (AGC) plays a major role to maintain system frequency at or very close to a specified nominal value, to sustain the scheduled exchange of power between the interconnected areas and to keep each unit's generation at the most economic value. Written works on detached and interconnected system worried with Automatic generation control of multi-region system have been accessible in the writing [1] - [5]. The ideas of demonstrating multi-area system have been presented by Elgerd and Fosha [1]; though Saikia et al. [2] have displayed a near investigation of a few established controllers, for example, Integral (I), Proportional-Integral (PI), Integral-Derivative (ID), Proportional-Integral-Derivative and Integral-Double Derivative. The investigations introduces a new classical controller, Integral-Double Derivative (IDD), which provides better dynamic performance than the others in two, three or five area thermal power system. Hamed Shabani et.al[5] has considered a strong PID controller for load frequency control. But all of them have investigated the system with thermal generation only.

Due to carbon emission issues and rapidly decreasing conventional energy resources, the need is to find some alternative sources so that energy needs can be met in near future. Solar energy and wind energy sources are such alternatives. Solar energy has large potential and according to recent studies, it may be energy source in near future. So the need is to integrate solar energy based power plant in AGC. The basic concepts of modelling and integration of renewable energy sources in AGC have been presented in literature [6]-[11]. H. Asano et.al [6] has invent the idea of integrating the pv system in AGC; whereas Bevrani et.al [7]-[8] have introduced new area control error (ACE) concept of AGC with renewable energy sources. BS Kumar [9] has introduced AGC for distributed generation. But their investigations are limited to photovoltaic system only while now a day's concentrated solar power (CSP) is growing rapidly. Li Wang et.al [10] has introduced the concept of solar concentrated grid connected ocean thermal energy conversion system. Dulal Ch. Das et.al [11] have presented the idea of incorporation of solar oriented thermal power plant in a separated force framework. But their investigations are limited to isolated system only. This needs further investigation.

The literature study reveals that authors have integrated photovoltaic system in two area interconnected system and integrated solar thermal power plant in isolated system only. No one has made comparative study of system in presence and in absence of solar thermal power plant. Several approaches namely Genetic algorithm (GA) [18],Particle Swarm optimization (PSO)[19], Bacterial foraging (BF)technique [20], and Artificial bees colony (ABC) [21] have been applied for optimization of controller gains in AGC. A meta heuristic algorithm called Firefly algorithm developed by Yang[18] has been used in AGC.

III. SYSTEM INVESTIGATED

The system considered in this paper is a three unequal area thermal system having solar thermal power plant in area-1. The capacity of area-1is 2000MW, area-2 is 4000 MW and area-3 is 8000 MW while solar thermal power plant has capacity of 300 MW. GRC is also considered for turbines for turbines of thermal system as 3% per minute. The governor speed regulation parameter is considered as 2.4 Hz/p.u.MW and frequency bias $B_i = \beta_i$ (AFRC).

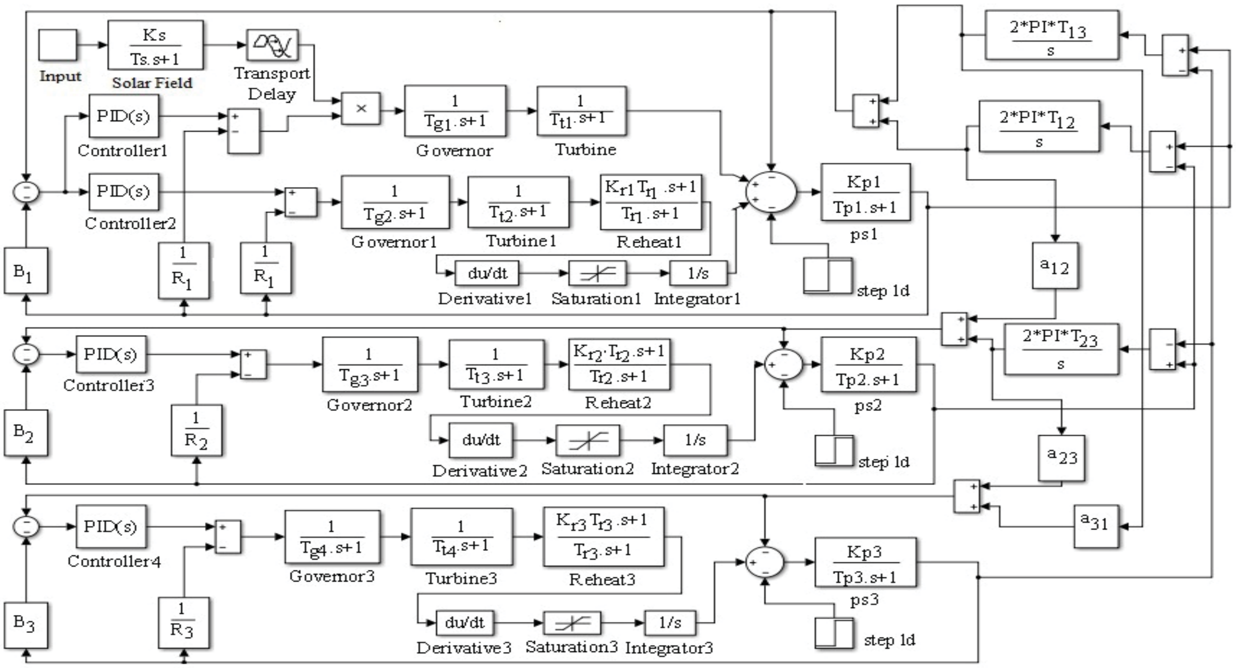

Figure.1 Three unequal area thermal system with STPP in area-1

The nominal parameters for thermal systems are taken from [2] and for solar thermal power plant from [10] and [11]. For interconnected system we have also considered three quantities $a_{12} = -P_{r1}/P_{r2}$, $a_{13} = -P_{r2}/P_{r3}$, $a_{23} = -P_{r1}/P_{r3}$. Several classical controllers such as I, PI and PID are considered for the analysis of the system investigation. The dynamic performances have been evaluated for 1% SLP in area-1. The system is shown in fig.(1). The controller gains are optimized using GWO technique. The investigation of execution is done utilizing minimization of the cost capacity given by mathematical statement (1)

$$J = \int_0^t \left\{ \left(\Delta f_i \right)^2 + \left(\Delta P_{tiei-j} \right)^2 \right\} dt \quad \text{.......(1)}$$ Where i, j= area number.

IV. SOLAR THERMAL POWER PLANT

Solar thermal technologies, otherwise called concentrating solar power (CSP), use warm vitality from the sun to produce power. CSP technologies track the sun on either one or two axes, and mirrors are arranged to focus the sunlight in either line-focus concentrators or point-focus concentrators. The high temperatures achieved at the focal point of the concentrators is used to heat an intermediate heat exchanging fluid, which can either be used for thermal energy storage, boiling water (for steam turbine), or powering thermal engines. Four types of CSP are currently being developed: parabolic trough, power tower, linear Fresnel reflector, and dish-Sterling (DS) designs. Parabolic trough, one of best invention of the CSP technologies. Today solar power tower and trough solar power are two STPS which has been look into and research about everywhere throughout the world.

They can be hybridized with wind, fossil fuel, and so forth. Trough sunlight based power plant comprises of expansive fields of parabolic trough gatherers with the bowing of single-course. Every gatherer has a straight parabolic formed reflector that centers the daylight onto a direct collector situated at the centre of the parabola to warmth working liquid (oil or water) in the pipes into some certain temperature (393C)[12]. Then, the steam is created by the heat transfer equipment and drive the steam turbine to generate electricity. Sun based power tower utilize high-temperature heat from concentrated sun based radiation by centering the radiation on a tower-mounted heat exchanger (recipient). The system comprises of huge quantities of sun-following mirrors called heliostats to mirror the occurrence daylight onto the recipient. The heat transfer fluids (water or other fluids) heated by solar thermal energy in the receiver heats water to generate high temperature steam (up to 560C) to drive the turbine to generate electricity. Currently, the total efficiency of the solar power tower that has been built is about 13%, and the efficiency of the sunlight collection and heat absorption is approximately 70%, as in [13].

The changing climate and the rotation of the day and night, requests heat stockpiling innovation to supply vitality constantly like fossil evaporator. In warmth stockpiling innovation the heat energy gathered by authority heats the working liquid in recipient, and in this manner thermal energy in the collector is gone to the thermal storage medium in the thermal storage compartment. There are three main thermal storage medium, molten salt, high temperature oil and water. On account of the capacity, power yield from the turbine generator stays steady through vacillations in solar intensity and until the greater part of the vitality put away in the hot tank is exhausted. Energy storage is vital for the accomplishment of solar power tower innovation, and liquid (molten) salt is accepted to be the way to practical medium of storage [14]. These plants are most appropriate for utility-scale applications in the 30–400 MW range [15]. At present, in Italy, Spain, Japan, France, and the United States test offices are worked to demonstrate that solar power tower based can deliver the power and to prove and improve on the individual system components The list of the solar thermal power stations include the 354 MW Solar Energy Generating Systems power installation in the USA Solar Power Station (Spain, 150 MW), Solnova ,solar oriented power station (Spain, 100 MW),Andasol, PS10 solar power tower (Spain, 11 MW), Nevada Solar One (USA, 64 MW), and PS20 solar power tower (Spain, 20 MW). The 968 MW Blythe Solar Power Project, situated in California's Mojave Desert, is the world's biggest solar thermal power plant extend as of now under development [16]. The solar thermal power industry is becoming quickly, with around 1.17 GW of concentrating solar power (CSP) plants online starting 2011[17] 582 MW of them are situated in Spain, and the United States has 507 MW of limit. Around 17.54 GW of CSP activities are a work in progress around the world, and the United States leads with around 8.67 GW. Spain positions second with 4.46 GW being developed, trailed by China with 2.5 GW [17].

V. FIREFLY ALGORITHMS

YANG PROPOSED A RECENT OPTIMIZATION TECHNIQUE, CALLED THE FIREFLY ALGORITHM (FA) [18,19]. THE ALGORITHM IDEALIZES THE NATURAL FLASHING CHARACTERISTICS OF FIREFLIES. THE SAID ALGORITHM FOLLOWS FEW ASSUMPTIONS:

(a) Unisexual characteristics of all fireflies, so that one firefly is attracted to other fireflies regardless of their sex.

(b) The higher intensity light attracts more. The attractiveness and brightness are inversely proportional to the distance.

(c) The brightness of a firefly is influenced by the objective function that has to be optimized. For a maximization problem, the brightness of flashing is directly proportional to that function.

The two issues that concern the FA are the light intensity variation and the effective formulation of the attractiveness. The objective function of the process is associated with the attractiveness of a firefly, which varies with brightness. To maximize the objective function, the brightness B of a firefly at a particular location y can be selected as B(y)/f(y). The attractiveness is relative property that should be observed by the other fireflies. Thus, it should change with the distance i-j between firefly i and firefly j. In the simplest form, the relation between the light intensity I(r) and the distance i-j is monotonic and exponential. This relation can be expressed in a mathematical way such that,

$$I=I_0 e^{-\gamma r} \quad (2)$$

Where actual light intensity and the light absorption coefficient is I_0 and γ, respectively. As a firefly's attractiveness is proportional to the light intensity seen by adjacent fireflies, we can now define the attractiveness β of a firefly by

$$\beta=\beta_0 e^{-\gamma r^2} \quad (3)$$

Where β_0 is the attractiveness at r= 0. The exponent γr can be replaced by other functions such γr^m as when m> 0. Schematically, the Firefly Algorithm (FA) can be summarized as the pseudo code as follows.

Objective function $f(x)$, $x=(x_1,.....x_d)^T$

Initialize a population of fireflies x_i (i= 1, 2, ...,n).

Define light absorption coefficient γ

While (t< Max Generation)

For i=1:n all n fireflies

For j=1:i all n fireflies

Light intensity I_i at x_i is determined by f(x_i)

if ($I_j > I_i$)

Move firefly i towards j in all d dimensions

end if

Attractiveness varies with distance via[- γr^2]

Evaluate new solutions and update light intensity

end for j

end for i

Rank the fireflies and find the current best

end while

In this FA based optimization, the parameters of FA technique are tuned for optimal performance and their tuned values are number of firefly=5, Maximum generation=100, β =0.2, α =0.5and γ =0.5.

VI. RESULT AND ANALYSIS

For this purpose the controller gains are optimized using Firefly algorithm in absence and presence of solar thermal power plant. In absence of solar thermal power plant the optimum values of controller gains with I controller are K_{I1}^{*} =0.73706, K_{I2}^{*}= 0.043334, K_{I3}^{*}= 0.39949, with PI controller are K_{P1}^{*}= 0.03129, K_{P2}^{*}= 0.015841, K_{P3}^{*}= 0.021688, K_{I1}^{*}=0.72698, K_{I2}^{*}=0.047255, K_{I3}^{*}= 0.40782 and with PID controller are K_{P1}^{*}= 0.619728, K_{P2}^{*}= 0.5, K_{P3}^{*}= 0.4971, K_{I1}^{*}= 1.0, K_{I2}^{*}= 0.99856, K_{I3}^{*}= 0.727193, K_{D1}^{*}= 0.4808462, K_{D2}^{*}= 0.5, K_{D3}^{*}= 0.50058. The dynamic performances corresponding to optimized controller gains are obtained and compared in fig.2. From fig.2, it is clear that PID controller is better than other controllers.

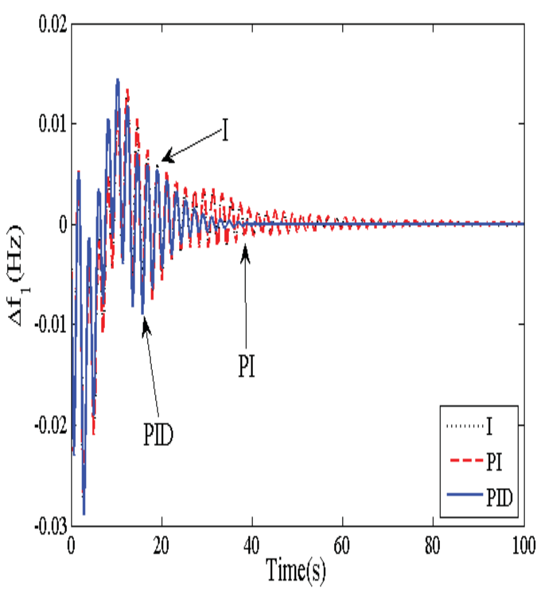

Figure.2 (a) Deviation in frequency in area-1

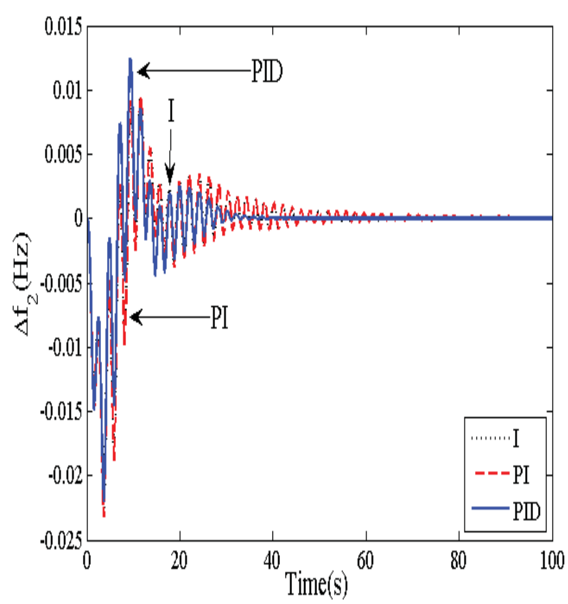

Figure.2 (b) Deviation in frequency in area-2

In presence of solar thermal power plant the optimum values with I controller are K_{I1}^{*}= 0.0031017, K_{I2}^{*}=0.77417, K_{I3}^{*}= 0.048162, K_{I4}^{*}= 0.40536, with PI controller are K_{P1}^{*}= 0.006759, K_{P2}^{*}=0.0095548, K_{P3}^{*}= 0.0052005, K_{P4}^{*}= 0.0075547, K_{I1}^{*}= 0.049368, K_{I2}^{*}=0.049368, K_{I3}^{*}= 0.32424, K_{I4}^{*}= 0.3014 and with PID controller are K_{P1}^{*}=1.0, K_{P2}^{*}= 0.6201303, K_{P3}^{*}= 0.7279677, K_{P4}^{*}= 0.9979621, K_{I1}^{*}= 0.2661, K_{I2}^{*}= 0.9683239, K_{I3}^{*}= 0.5193985, K_{I4}^{*}= 0.5, K_{D1}^{*}= 0.999827, K_{D2}^{*}= 0.5, K_{D3}^{*}= 0.626261, and K_{D4}^{*}=0.974298. The dynamic performances corresponding to optimized controller gains and in presence of solar thermal power plant are obtained and compared in fig.3. It is clear that PID controller gives better result.

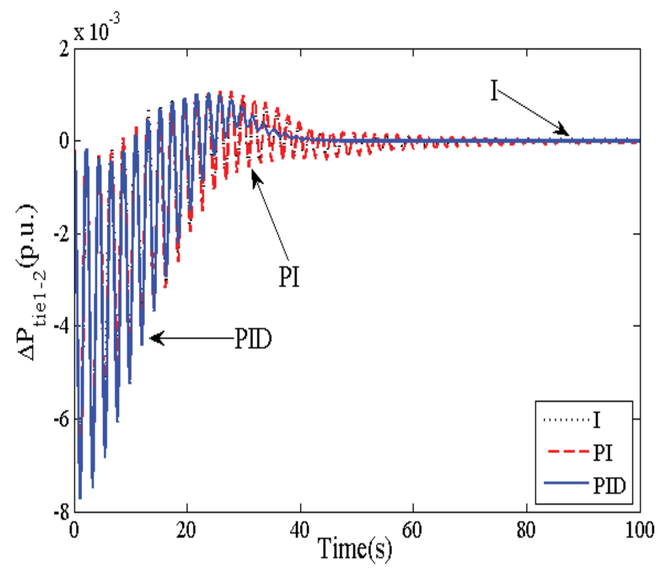

Figure 2(c) Deviation in tie power area 1 and area 2

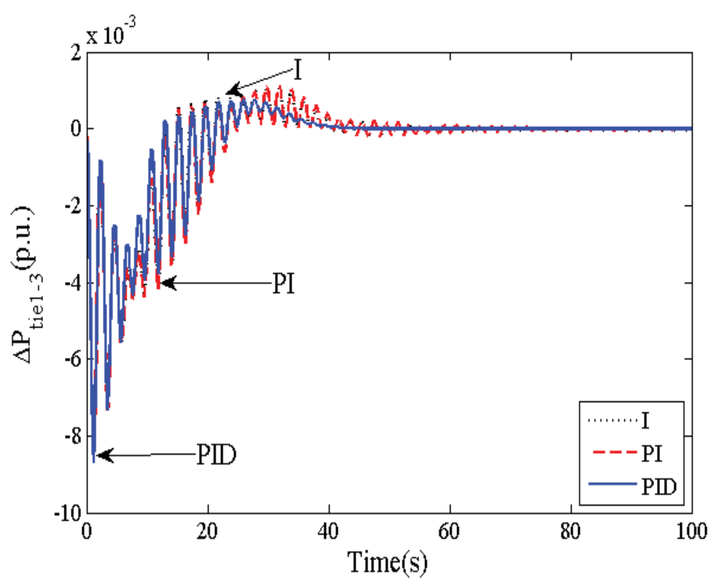

Figure 2(d) Deviation in the power area 1 and area 3

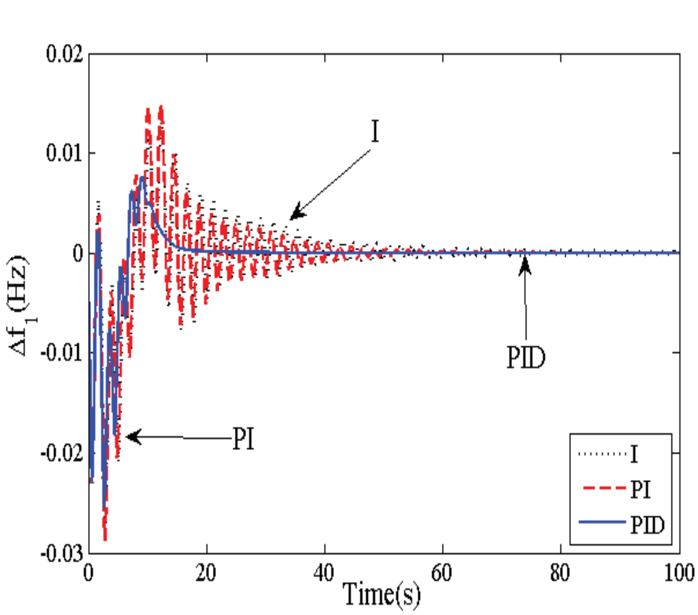

Figure.3(a) Deviation in frequency in area-1

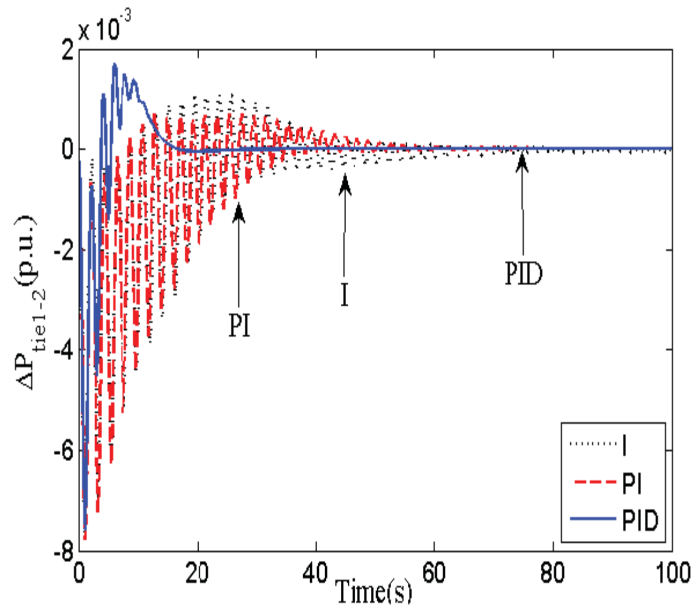

Figure.3(b) Deviation in tie power connecting area-1 and area-2

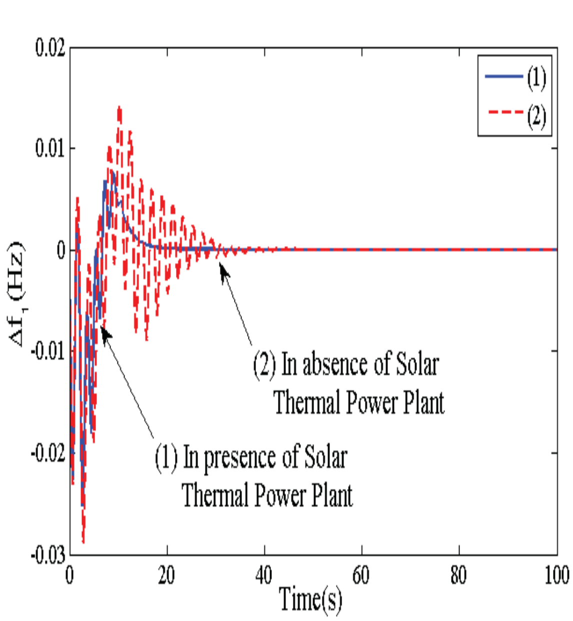

Figure.4 (a) Deviation in frequency in area-1

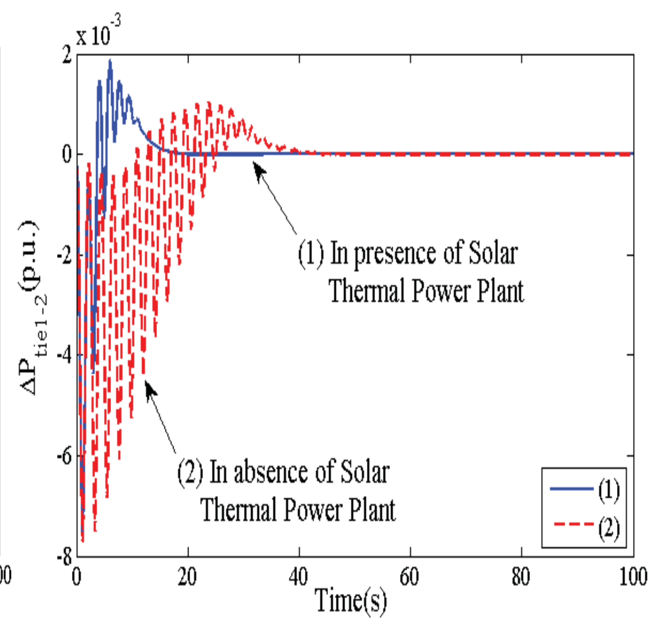

Figure.4 (b) deviation in tie power connecting area-1 and area-2

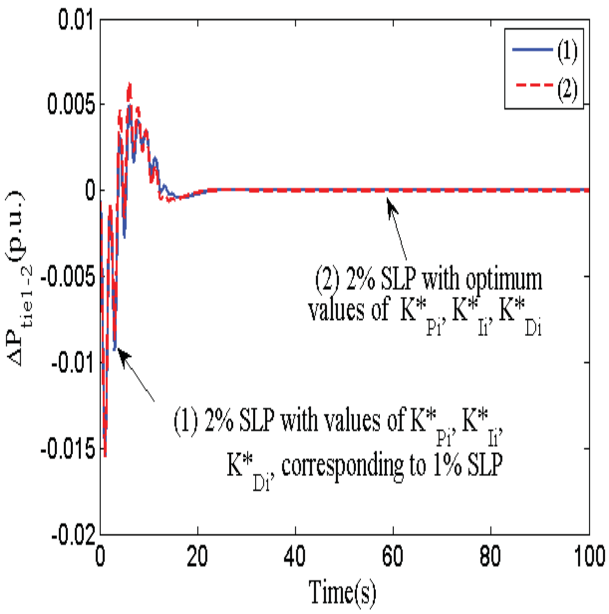

Figure.7 Deviation in frequency in area-1

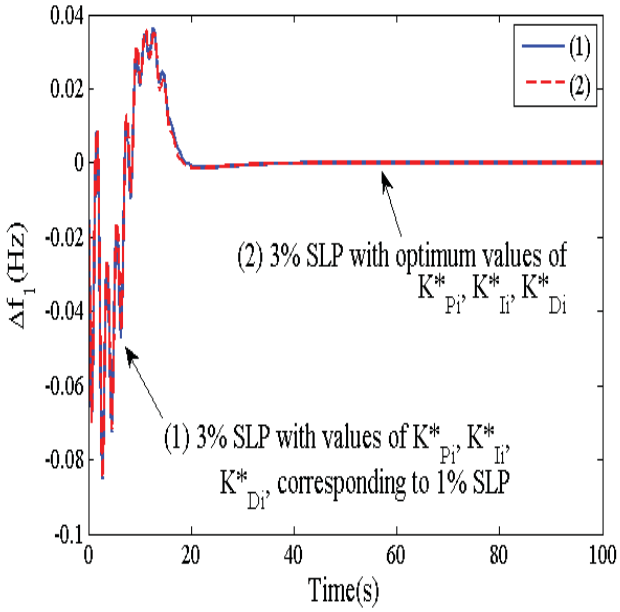

Figure.8 Deviation in tie power connecting area-1 and area-2

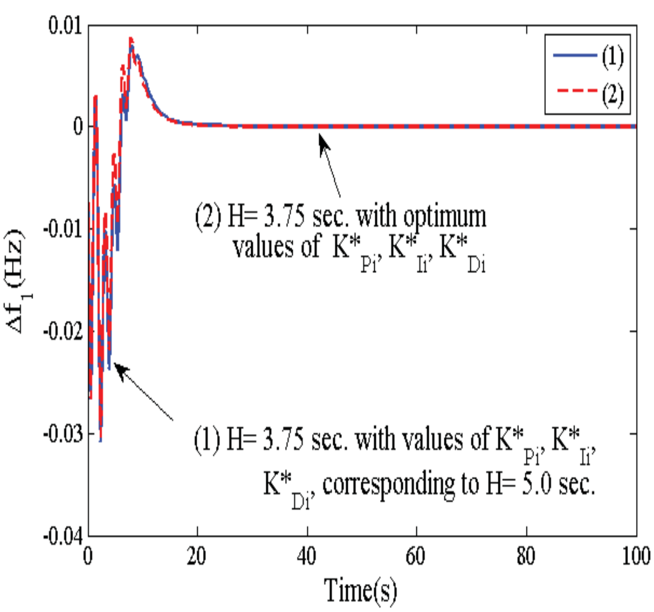

Fig.9 Deviation in frequency in area-1

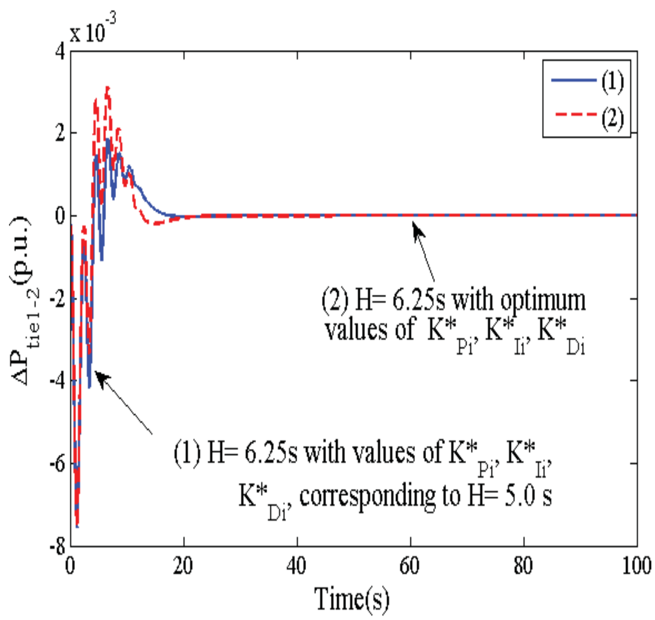

Fig.10 Deviation in tie power connecting area-1 and area-2

Again the dynamic performances of system with PID controller in absence and presence of solar thermal power plant with corresponding optimized controller gains are compared and shown in Fig.4. It is clear from figure that PID controller in presence of solar thermal power plant gives better result in terms of settling time, peak overshoot and magnitude of oscillations.

Sensitivity analysis has also been carried out to see the robustness of the optimum gains of PID (K_{Pi}*, K_{Di}*, K_{Ii}*) obtained at nominal loading (50% of area capacity) conditions (shown in Appendix) to wide changes in system loading conditions, system inertia constant(H) and the magnitude of SLP. For this, simultaneous optimization of K_{Pi}, K_{Di}, and K_{Ii}, is done for ±25% change in system loading from nominal, for ±25% change in system inertia constant and at changed magnitude of SLP (1%, 2%, 3%) using GWO. The values of settling time, peak overshoot and undershoot are noted from the Fig.5. The dynamic responses of the system with K_{Pi}*, K_{Di}*, K_{Ii}* corresponding to changed condition and nominal conditions are compared and shown in Fig.6, Fig.7, Fig.8, Fig.9,

Fig.10. From critical observations of the dynamic responses, it is clear that responses are more or less same. Thus, the parameters obtained at nominal conditions need not be reset for wide changes in system loading conditions, size of SLP and system inertia constant (H).

VII. CONCLUSION

A disentangled model of solar based thermal power plant has been created and joined in AGC. FA technique has been used for first time in AGC to optimize the gains of controller. Analysis reveals that FA optimized PID controller gives the better results. Sensitivity analysis reveals that FA optimized PID controller is quiet robust and need not to reset for a wide change in nominal conditions of the system i.e. stacking and other system parameters.

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