Automatic Generation Control Of A Solar-Thermal Deregulated Power System With Hydrogen Energy Storage Unit

V. Suresh Babu, K. Shanmukha Sundar

Abstract:The proposed research article presents an optimum Fractional-Order Proportional-Integral-Derivative (FOPID) controller based Automatic Generation Control (AGC) in a two-area interconnected deregulated power system which includes renewable sources of energy like solar thermal power generating units. In this investigation, the thermal plants are considered with reheat tandem compound steam turbine rather than steam turbine dynamic model parameters are thought to be consistent. Concentrated solar power can store vitality in the type of thermal energy. The stored thermal energy can be utilized to produce electricity in absence of solar irradiance. Thus, AGC of multi-area power system incorporating solar thermal power plant (STPP) is vital for these examinations. FOPID controller is an established Proportional-Integral-Derivative (PID) controller aside from its derivative and integral orders are fractional numbers in place of being integers. The tuning of the FOPID controller parameters is formulated as an optimization problem and solved by employing a Lightning Search Algorithm (LSA). Further to enhance the AGC execution, Hydrogen Energy Storage (HES) is incorporated into its control area. The simulation results reveal that the supremacy of projected FOPID controller, the dynamic performance of AGC loop have improved in terms of less peak deviation and settling time of area frequencies and tie-line power oscillations in various exchanges of deregulated power system is compared with Proportional-Integral (PI), Proportional-Integral Derivative (PID) controller based AGC loop. The execution of HES unit effectively damp the electromechanical oscillations in a power system, as they provide ensure from the storage capacity in addition to the kinetic energy of the generator rotors which can share sudden changes in power requirement. The Power flow control by HES unit is also found to be efficient and effective for improving the dynamic performance of AGC loop for a two-area solar thermal interconnected power system

Index Terms:Area Control Error , Automatic Generation Control, Disco Participation Matrix, FOPID controller, Hydrogen Energy Storage unit, Lightning Search Algorithm, solar thermal power plant.

1 INTRODUCTION

In the present scenario, power system is adopting the deregulated market operation which consists of generating companies (Gencos), transmission companies (Transcos), distribution companies (Discos), and an independent contract administrator (ICA). Thus, transforming the vertically integrated utilities to horizontally ones and thereby introducing competition among the players. In restructured environment, all Gencos are not bound to take part in Automatic Generation Control (AGC) and Discos are independent of choosing any Genco from either its own control area or others, to maintain the load demand. The ICA responsibly supervises the power transactions among the players to provide reliable operation of the power system. Several type of transactions are present in the market namely the bilateral contracts, poolco based transactions, and area regulation contracts [1]. The AGC activity is coordinated by the Area Control Error (ACE) which is a job of system frequency and tie line power flows. As the ACE is engaged to zero by the AGC both recurrence and tie-line control blunders will be put on to zero [2]. An ICA is a self-overseeing specialist that deals with every one of the exchanges accepted among Discos and Gencos. A Disco Participation Matrix (DPM) is utilized for the pipedream of bonds among Gencos and Discos. An ICA needs to perform different auxiliary administrations for winning activity of the power system [3].

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The ideas of the mix of solar thermal power plant (STPP) for AGC ponder, be that as it may, their investigation is confined to a detached system just and they have not connected any control methodology for STPP [4, 5]. The solar energy is a spotless energy accessible in copious. Conversion of solar energy into electric energy does not discharge ozone-depleting substances. Additionally, the utilization of this nonconventional energy diminishes the utilization of regular well springs of energy. Hence, AGC of multi-area system incorporating solar thermal power plant (STPP) is important for further studies. The performance of PID controllers can be improved by using the fractional calculus. In fractional order (FO) controllers, the order of integral and derivative terms is not an integer [6]. The main advantage associated with FO controllers is flexibility in controlling purpose which helps to design a robust control system. FO controllers have excellent capability of handling parameter uncertainty, elimination of steady state error and better stability [7]. In this study FOPID controllers are being used for the AGC loop of a two area interconnected solar thermal deregulated power system. A later intense meta-heuristic algorithm called Lightning Search Algorithm (LSA) is a great and adaptable advancement strategy that was propelled by the characteristic wonder of lightning [8, 9]. The advantages of this algorithm are to be used for optimization of FOPID controller gains of AGC loop for two-area solar-thermal interconnected deregulated power system for different transactions. The energy storage devices such as HES unit using Automatic Generation Control problem can effectively damp the electromechanical oscillations in a power system, as they provide ensure from the storage capacity in addition to the kinetic energy of the generator rotors which can share sudden changes in power requirement. HES unit is a vigorous power source which can be vital not just as a quick energy compensation device for power use of gigantic loads yet additionally as a stabilizer of frequency oscillations [10]. The HES unit have been remunerated an amassing of load and could keep up power quality for deregulated control supplies. Whatever is left of the paper is composed as pursues: (a) to design a two-area solar-thermal deregulated power system having different capacities (b) to outline and upgraded PID and FOPID controller utilizing LSA and dissect the dynamic execution for AGC loop in deregulated power system (c) to study the effect of HES in AGC studies (d) to test the effectiveness of proposed controllers in a two-area solar-thermal deregulated power system with HES unit.

2 DESIGN OF FOPID CONTROLLER USING LIGHTNING SEARCH ALGORITHM

2.1 Controller structure of FOPID controller

The block diagram of Fractional Order PID (FOPID) controller, referred to as $PI^{\lambda}D^{\mu}$ controller is shown in Fig.1. In FOPID controller, in addition to K_P, K_I and K_D there are two more parameters λ and μ, the integral and derivative orders respectively. The transfer function of proposed FOPID controller is given (1) $T(s) = K_P + \frac{K_I}{s^{\lambda}} + K_D s^{\mu} \qquad \lambda, \mu > 0$
(1)

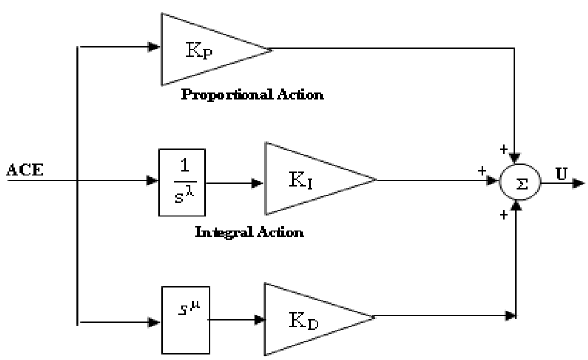

Fig. 1. *Block diagram for FOPID controller*

On the off chance that λ=0 and μ=0, at that point it is simply just a proportional (P) controller, If λ=0 and μ=1, at that point it turns into a proportional-derivative (PD) controller, If λ=1 and μ=0, at that point it turns into a proportional-integral (PI) controller and If λ=1 and μ=1, at that point it moves toward becoming whole number PID. These whole number request controllers are spoken to as focuses in the λ-μ plane as appeared in Fig. 2 (a). Accordingly FOPID controller sums up the PID controller and extends it from point to whole λ-μ plane as appeared in Fig. 2 (b) hence offering the significantly more extensive determination of tuning parameters subsequently greater adaptability in the controller configuration prompting more exact control. The LSA methods are utilized to decide the ideal requirements of PI, PID and FOPID controllers with the target to limit the Integral square of area control error, which can be defined in the accompanying way: $J = \int_0^{t_{sim}} (\beta_1 \Delta F_1^2 + \beta_2 \Delta F_2^2 + \Delta P_{tie}^2)\, d$ (2)The problem constraints are the proposed controller parameter bounds. Therefore, the design problem can be formulated as, $Minimize\, J$ (3) Subject to $K_P^{min} \le K_P \le K_P^{max}, K_I^{min} \le K_I \le K_I^{max}, K_D^{min} \le K_D \le K_D^{max}, K_{FR}^{min} \le K_{FR} \le K_{FR}^{max}, N^{min} \le N \le N^{max}, \lambda^{min} \le \lambda \le \lambda^{max}, \mu^{min} \le \mu \le \mu^{max},$
(4)

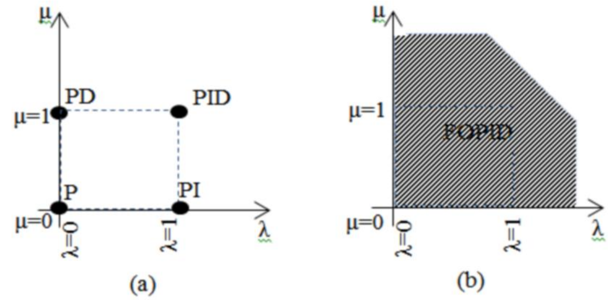

Fig. 2 *(a) Integer order P/PI/PD/PID controllers (b) Fractional order PID controller*

2.2 Lightning Search Algorithm

LSA is a natural phenomenon based on a novel meta-heuristic algorithm. It is based on the lightning mechanism which involves the propagation of step leader [9]. Some of the molecules of water condensed from a thundercloud split in random directions, known as projectiles. It is considered that the fast particles called projectiles form the binary tree structure of the step leader. The initial population size of the algorithm is represented by these projectiles. The velocity of the projectile is shown in (5) $v_p = \left[1 - \left(\frac{1}{\sqrt{1-\left(\frac{v_0}{c}\right)^2 - \left(\frac{sF_i}{mc^2}\right)}}\right)^{-2}\right]^{-1/2}$
(5) Where v_0 is the initial velocity of the projectile, *m* is the mass of the projectile, F_i is the constant ionisation rate, *c* is the speed of light and *s* is the length of the path travelled. Thus, the projectile has less potential to ionise or explore a large space if the mass is less and travelled path is long. Hence, the relative energy of the step leader controls the exploration and exploitation of the algorithm. An important property of projectile is forking, which improves the bad solution of the population and if it is not so one of the channels at the forking point is lighted up to keep the population size. In this algorithm, three types of projectiles are introduced to represent the whole step leader movement. These are transition projectiles which construct the population of first step leader, space projectile which try to attain the best position and lead projectile which represents the best position among all population. Since the transition projectiles are ejected in random direction, it can be represented by a random number from uniform probability distribution function, which is given by (6) $f(x^T) = \begin{Bmatrix} \frac{1}{b-a}; & a \le x^T \le b \\ 0 \quad ; & x < a, x^T > b \end{Bmatrix}$ (6) Where x^T is the random number that gives the solution or the initial tip energy of step leader *i*, *a* and *b* are the lower and upper boundaries of the solution space. After evolving the *N* step leader tips, it will move by ionising the surrounding area of the old leader using energetic projectiles in the next step. The position of the space projectile can be obtained from probability density function of exponential distribution as shown in (7) $f(x^s) = \begin{Bmatrix} \frac{1}{\mu} e^{-x^s i \mu}; & a < x^T < b \\ 0 \quad ; & x^s \le 0 \end{Bmatrix}$ (7) Where, *μ*- is the shaping parameter which determines the space projectile position or direction in the next step. For a particular space projectile, μ_i is considered as the distance between lead projectile and space projectile in the algorithm. The position of a particular space projectile is given by (8) $P_{i-new}^s = P_i^s \mp \exp rand_i\,(\mu_i)$

(8) If the projectile energy is not greater than the step leader, the new position of the space projectile does not ensure propagation of stepped leader to expand the channel. If it is not so, it will become lead projectile. The normal probability distribution function of lead projectile with scale parameter σ is given by (9) $f(x^L) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(x^L-\mu)^2/2\sigma^2}$ (9) In LSA, the best solution can be obtained as shape parameter for space projectile and scale parameter decreases exponentially. The position of lead projectile is expressed in (10).$P_{new}^L = P^L + normrand_i(\mu_L, \sigma_L)$ (10) If the new position of the lead projectile gives a good solution, then the step leader is extended and the lead projectile position is updated. Thus, the exploitation and exploration are performed by space and lead projectiles to find the optimum solution. The exploration is represented by exponential random behaviour of the space projectile and exploitation process is controlled by lead projectile with random search. The control parameters of LSA are population size, maximum iteration and channel time. In this study, population size, maximum iteration and channel time are considered as 100, 100 and 20, respectively.

3 MATHEMATICAL MODELING OF HYDROGEN ENERGY STORAGE (HES) UNIT

Hydrogen is one of the promising alternatives that can be used as an energy carrier. The universality of hydrogen implies that it can replace other fuels for stationary generating units for power generation in various industries. Having all the advantages of fossil fuels, hydrogen is free of harmful emissions when used with dosed amount of oxygen, thus reducing the greenhouse effect. Essential elements of a hydrogen energy storage system comprise an electrolyzer unit which converts electrical energy input into hydrogen by decomposing water molecules, the hydrogen storage system itself and a hydrogen energy conversion system which converts the stored chemical energy in the hydrogen back to electrical energy as shown in Fig 3.The transfer function of the Aqua Electrolyzer can be expressed as first order lag: $G_{AE}(s) = \frac{K_{AE}}{1+sT_{AE}}$ (11) The transfer function of Fuel Cell (FC) can be given by a simple linear equation as $G_{FC}(s) = \frac{K_{FC}}{1+sT_{FC}}$ (12) The overall transfer function of hydrogen Energy storage unit has can be $G_{HES}(s) = \frac{K_{HES}}{1+sT_{HES}} = \frac{K_{AE}}{1+sT_{AE}} \times \frac{K_{FC}}{1+sT_{FC}}$ (13)

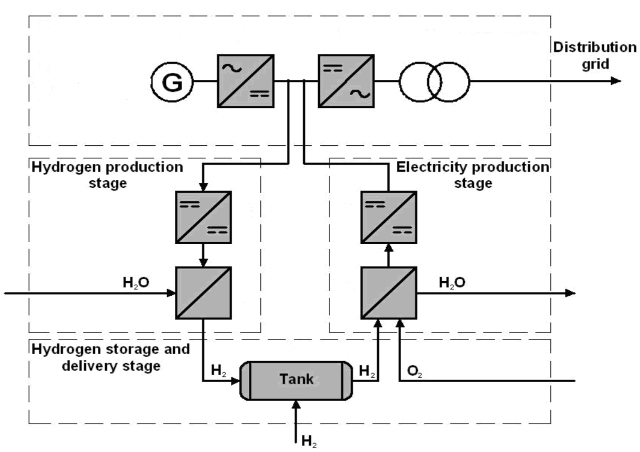

Fig. 3 *Block diagram of the hydrogen storage unit*

4 MODELING OF STPP IN DEREGULATED ENVIRONMENT

The Linearized model of two- area two-area solar-thermal power system interconnected restructured power system with HES unit are considered for the study as shown in Fig.4. The AGC execution is acknowledged on the steam turbine dynamic model parameters. The steam turbine show parameters are observed to be dependent on the generation schedules of thermal power plants [11]. The dynamic models of reheat bicycle mix condensation turbine are appeared in Fig 5. The principle requirements of these models are the time constants T_{SC}, T_{RH} and T_{CO} of Steam Chest (SC), Reheater (RH) and Cross-Over (CO) pipe respectively and the power divisions F_{HP}, F_{IP} and F_{LP} of High Pressure (HP), Intermediate-Pressure (IP) and Low Pressure (LP) turbines separately. The regular estimations of different time constants and power bits of thermal reheat turbine can be intended for various generation schedules by expelling the heat balance data is appeared in the appendix [11]. In the new environment, Discos may contract power from any Gencos and ISO has to supervise these contracts. DPM is a matrix in which the number of rows is equal to the number of Gencos and the number of columns is equal to the number of Discos in the system Each entry in this matrix can be considered for the portion of a total load contracted by a Disco towards a Genco. The sum of all the entries in a column DPM is unity. From the Fig 4, Let Genco1, Genco2, Disco1, Disco2 be in area 1 and Genco3, Genco4, Disco3, Disco4 be in area 2. The corresponding DPM is given as follows

$$DPM = \begin{bmatrix} cpf_{11} & cpf_{12} & cpf_{13} & cpf_{14} \\ cpf_{21} & cpf_{22} & cpf_{23} & cpf_{24} \\ cpf_{31} & cpf_{32} & cpf_{33} & cpf_{34} \\ cpf_{41} & cpf_{42} & cpf_{43} & cpf_{44} \end{bmatrix} \quad (14)$$

where *cpf* represents "contract participation factor" i.e. p.u. MW load of a corresponding Disco. The scheduled steady state power flow on the tie-line is given as [1] $\Delta P_{Tie\ 12}^{scheduled} = \sum_{i=1}^{2}\sum_{j=3}^{4} cpf_{ij}\,\Delta P_{Lj} - \sum_{i=3}^{4}\sum_{j=1}^{2} cpf_{ij}\,\Delta P_{Lj}$ (15) The actual tie-line power is given as $\Delta P_{Tie\ 12}^{actual} = \frac{2\pi T_{12}}{s}(\Delta F_1 - \Delta F_2)$ (16) At any given time, the tie-line power error is given by [1] $\Delta P_{Tie\ 12}^{Error} = \Delta P_{Tie\ 12}^{actual} - \Delta P_{Tie\ 12}^{scheduled}$ (17) $\Delta P_{Tie\ 12}^{Error}$ vanishes in the steady as the actual tie-line power flow reaches the scheduled power flow. This error signal is used to generate the respective Area Control Error (ACE) signals as in the traditional scenario [1]. The generation of each Genco must footpath the contracted demands of Discos in steady state. The desire total power generation of i^{th} Genco interms of DPM entries can be calculated as $\Delta P_{mi} = \sum_{j=1}^{4} cpf_{ij}\,\Delta P_{Lj}$ (18) As there are two Gencos in every area, the ACE signal must be scattered among them in proportion to their participation in the AGC. Coefficients that circulate ACE to Gencos are named as "“ACE Participation Factors (apfs)”. In a given control territory, the entirety of the participation factors is equal to 1. Consequently, apf_{11}, apf_{12} are considered as ACE participation factor in area 1 and apf_{21}, apf_{22} are in area 2.

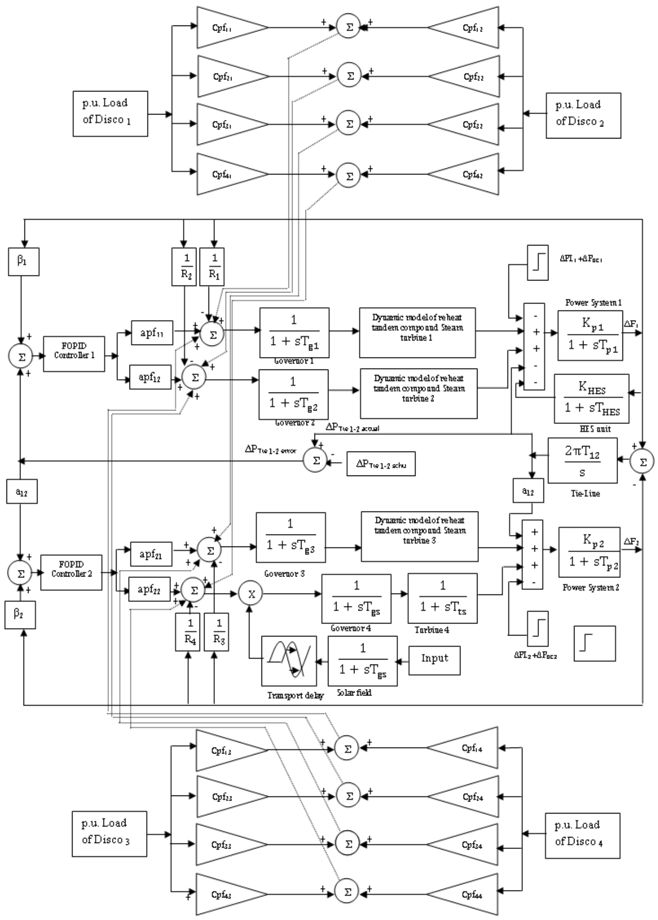

Fig. 4 *Transfer function model of two area solar-thermal power system with HES unit in deregulated environment*

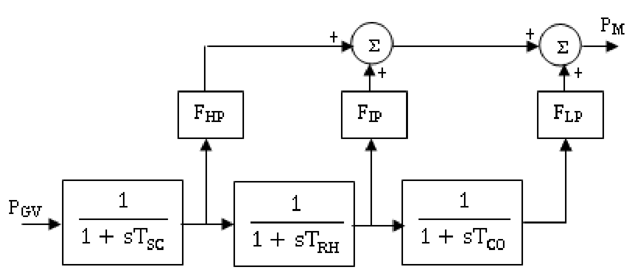

Fig. 5 *Dynamic model of a reheat tandem compound steam turbine*

5 Simulation Results and Observations

In this test system consists of two Gencos and two Discos in each area. The two thermal reheat tandem compound steam turbine units are Gencos in area-1 and solar and thermal units as Gencos in area-2 are shown in Fig 4. The proposed FOPID controller is tuned using Lightning Search Algorithm (LSA) technique and implemented two-area solar-thermal interconnected deregulated power system for different transactions. In this test system consists of two Gencos and two Discos in each area. The nominal parameters are given in Appendix. The optimal solution of control inputs is taken for optimization problem and the objective function in Eqn (2) is derived using the frequency deviations of control areas and tie- line power changes. The model of the framework under investigation has been created in MATLAB/SIMULINK condition. The dynamic power model of HES unit is introduced in area1 to analyze its impact on the power system performance. Scenario 1: Poolco based transaction In this scenario, Gencos participate only in the load following control of their areas. It is assumed that a large step load 0.1 p.u MW is demanded by each Disco in area 1. Assume that a case of Poolco based contracts between Dicos and available Gencos is simulated based on the following Disco Participation Matrix (DPM) referring to Eqn (14) is considered as $DPM =$

$$\begin{bmatrix} 0.5 & 0.5 & 0.0 & 0.0 \\ 0.5 & 0.5 & 0.0 & 0.0 \\ 0.0 & 0.0 & 0.0 & 0.0 \\ 0.0 & 0.0 & 0.0 & 0.0 \end{bmatrix} \quad (19)$$

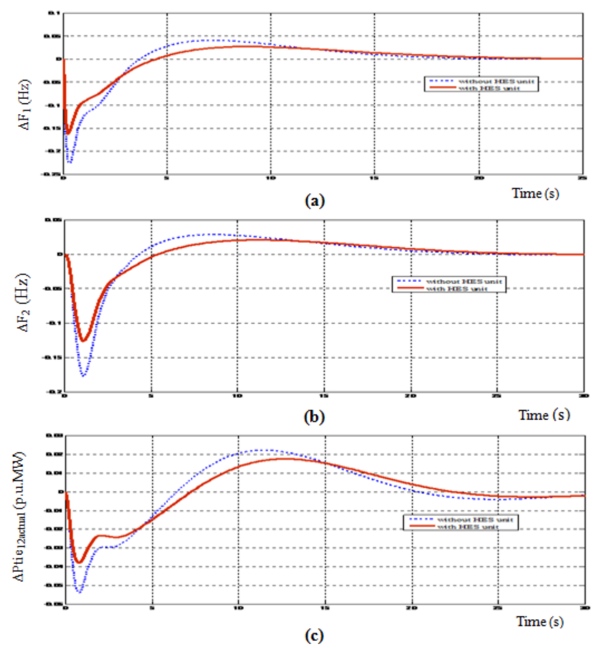

Fig. 7. *Dynamic responses of the frequency deviations, and tie-line power deviations, for a two area solar-thermal system using FOPID controller without and with HES units (Poolco based transaction)*

$Disco_1$ and $Disco_2$ demand identically from their local Gencos, viz., $Genco_1$ and $Genco_2$. Therefore, $cpf_{11} = cpf_{12} = 0.5$ and $cpf_{21} = cpf_{22} = 0.5$. The ideal FOPID controller gain estimations of test system without and with HES unit for different contextual analyses are recorded in the Table1. These FOPID controllers are executed in a proposed test system for various types of transactions with various generations schedules and contrasted and PI and PID controllers. In Fig 6 shows comparative transient performances of solar-thermal power system for given load perturbation. From the Fig 6, it can observed that the oscillations in the area frequencies and tie-line power deviations have decreased to a considerable extent with LSA tuned FOPID controller when compared the output responses obtained using PI and PID controllers. The dynamic power model of HES unit is introduced in area1 to analyze its impact on the power system performance. The ideal FOPID controller gain estimations of test system with HES unit for different contextual analyses. From the simulated results is appeared in Fig 7, it is seen that the restoration procedure with the HES unit ensures not only reliable operation but provides a good margin of stability compared with the test system without

TABLE 1

OPTIMUM VALUES OF CONTROL PARAMETERS OF VARIOUS CONTROLLERS UNDER DIFFERENT TYPES TRANSACTIONS

controller	Gain/ parameters	Poolco based transactions		Bilateral based transactions	
		Area-1	Area-2	Area-1	Area-2
PI	K_{Pi}	0.33	0.281	0.327	0.273
	K_{Ii}	0.417	0.374	0.407	0.371
PID	K_{Pi}	0.446	0.387	0.448	0.454
	K_{Ii}	0.535	0.401	0.512	0.483
	K_{Di}	0.634	0.498	0.547	0.591
FOPID	K_{Pi}	0.543	0.447	0.562	0.553
	K_{Ii}	0.602	0.568	0.537	0.528
	K_{Di}	0.942	0.616	0.723	0.596
	λ_i	0.879	0.976	0.745	0.758
	μ_i	0.568	0.645	0.467	0.571

HES units.Scenario 2: Bilateral based transaction Here every one of the Discos has the contract with the Gencos and the accompanying Disco Participation Matrix (DPM) alluding to Eq (14) is considered as $DPM_2 = \begin{bmatrix} 0.2 & 0.3 & 0.1 & 0.4 \\ 0.3 & 0.2 & 0.3 & 0.1 \\ 0.25 & 0.1 & 0.25 & 0.3 \\ 0.25 & 0.4 & 0.35 & 0.2 \end{bmatrix}$ (20) For this situation, the $Disco_1$, $Disco_2$, $Disco_3$ and $Disco_4$, requests of 0.1 pu.MW for each from Gencos as characterized by cpf in the DPM and each Gencos takes an interest in AGC as characterized by the accompanying area participation factor $apf_{11} = apf_{12} = 0.5$ and $apf_{21} = apf_{22} = 0.5$. The optimal values of corresponding controller's parameters are tabulated in Table 1 and the comparative dynamic responses are shown in Fig 8.From the results show that FOPID controller is performing improved in comparison to rest of the controllers because of smaller peak variations and time to settle. The main merit of FOPID controller has good stability for different transactions, excellent transient and dynamic responses in comparison with PI, PID controllers. The above analysis revealed that FOPID controller has less peak deviation, magnitude of oscillations, and faster settling time than others in all the transactions and shows superior performance for controlling of system oscillations. Thus, FOPID can be used as suitable secondary controller in AGC loop for two area solar-thermal deregulated power system.

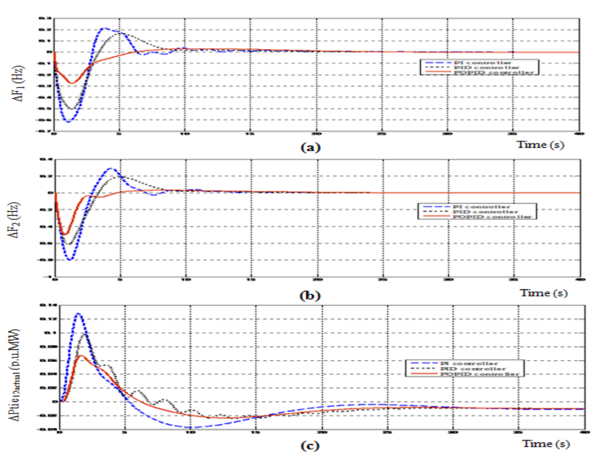

Fig.8. *Dynamic responses of the frequency deviations, tie-line power deviations, for a two area solar-thermal system using different types controllers (Bilateral based transaction)*

6 Conclusion

Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions. Authors are strongly encouraged not to call out multiple figures or tables in the conclusion—these should be referenced in the body of the paper. The FOPID controllers are designed to utilize LSA strategy and acknowledged in two area solar-thermal interconnected power system without and with HES units for different types transactions. The various simulated results demonstrate that the proposed FOPID controller's execution is quick, more precise and superior to the reenacted results with PI and PID controllers. HES unit is incorporated into area1 so as to enhance the system performance. It is seen that in every one of the cases (poolco based, bilateral based and contract violation based) the deviation of frequency ends up zero in the enduring state with less setting time as a result of the organized use of HES units which guarantees the prime necessity of AGC. The investigation likewise uncovers that the LSA strategy is more precise, solid and proficient in finding global optimal solution than other improvement algorithms. The proposed FOPID controller with AGC system has HES units that exhibit better execution to provide reduce the restoration time, thereby improving the system reliability.

References

[1] V. Donde, M.A. Pai, I.A. Hiskens, Simulation and optimization in an AGC system after deregulation, IEEE Transactions on Power System, Vol. 16, No.3, pp.311-322, 2010.

[2] Elgerd, O.I. "*Electric energy systems theory: an introduction*". Tata McGraw Hill Education Pvt. Ltd, New Delhi, India, 2014.

[3] Pardeep Nain, K.P.Singh Parmar and A.K. Singh, "Automatic Generation Control of an Interconnected Power System Before and After Deregulation", International Journal of Computer Applications, Vol. 61, No.15, pp.11-16, 2013.

[4] Yatin Sharma and Lalit Chandra Saikia, "Automatic generation control of a multi-area ST – Thermal power system using Grey Wolf Optimizer algorithm based classical controllers", International Journal of Electrical Power & Energy Systems, Vol.73, pp.853-862, 2015.

[5] Baskar, B., and B. Paramasivam, "FOPID controller based AGC loop of a two-area Solar-Thermal deregulated Power System with Vanadium Redox Flow Battery", International Journal for Research in Engineering Application & Management (IJREAM), Vol.4, Issue-12, pp.245-253, 2019.

[6] Wei, Y.H; Sun, Z. Y.; Hu, Y. S,; and Wang, Y. " On fractional order adaptive observer", *International Journal of Automation and Computing*. Vol.12, No.6, pp,664–670, 2015.

[7] Swati, S; Yogesh, V.H., "Fractional order PID controller for load frequency control", *Energy Conversion and Management*, Vol.85, pp.343–353, 2014.

[8] Shareef, H.; Ibrahim, A.A.; and Mutlag, A.H, "Lightning search algorithm", *Applied Soft Computing*, Vol.36, pp.315-333, 2015.

[9] Rajbongshi, R.; and Saikia, L.C, "Combined control of voltage and frequency of multi-area multisource system incorporating solar thermal power plant using LSA optimised classical controllers. *IET Generation, Transmission & Distribution*, Vol.11, No.10, pp.2489-2498, 2017.

[10] K. Chandrasekar, B. Paramasivam and I.A. Chidambaram, "Ancillary Service Requirement

Assessment Indices Evaluation with Proportional and Integral plus Controller in a Restructured Power System with Hydrogen Energy Storage Unit", Middle-East Journal of Scientific Research, Vol. 24, No. 12, 2016, pp. 3838-3857.

[11] Nikhil Pathak, Ashu Verma, and Terlochan Singh Bhatti, " Automatic generation control of thermal power system under varying steam turbine dynamic model parameters based on generation schedules of the plants", The Journal of Engineering, Vol.24, pp.1-13, 2016.