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Research Paper

Automatic generation control of a two area power system implementing IDDF controller under restructured environment

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Abstract

This paper presents the Automatic generation control of an interlinked power system in a restructured environment. The model consists of a hydro plant, a thermal plant and a diesel plant incorporated in both areas. The Area Control Error (ACE) is minimized with the help of a new controller called the Integral Double Derivative controller (IDDF) employed as a secondary controller in the proposed model. The controller parameters are optimized by a novel optimization scheme called the Lightning Search Algorithm. The proposed model is simulated under two market scenarios. The robustness of the system is also examined under step load perturbations, random loading conditions and parameter variation. The settling time of the IDDF controller is put to comparison with the PID controller and the supremacy is established.

Keywords: *AGC; Deregulated; IDDF; Load Frequency Control; LSA; Multi- Source; PID; Restructured Environment.*

1. Introduction

In power system environment, Automatic generation control (AGC) compares to the adjustment of the output power of alternators in response to the load changes. The whole power system's effectiveness is reached by maintaining equilibrium between power generations with load consumptions along with system losses. The entire power system's frequency, voltage and tie line power due to changes in abnormalities and demand that leads to imbalance of the system. In this case, AGC comes into scene to make the entire system's frequency and deviation of power in the tie-line to zero to make the power system stable. [1-2]

The important goals of AGC are frequency changing due to the step load perturbation should be zero. The change in steady state tie line power flow should be zero. The time error should be very less in order to provide power to the area in need of emergency.

Various researches have been done in the case of AGC during last decades. In paper [3], an effort has been made for connecting AGC and Economic Dispatch from an optimization view. In paper [4], a biogeographic search method known as hybrid pattern method of a multi-area system in AGC has been done. In paper [5], an effort has been made for the model and survey of fuzzy PID controller comprised of a imitative filter in a multi-area of automatic generation control. In paper [6], an optimization technique called as learning based optimization has been done for Optimal PD-PID cascaded controller based AGC of a multisource interconnected power system. The paper [7] describes a thermal system in four unequal area of AGC by use of distribution based optimised 3DOF-PID controller. In Paper [8], an effort has been done for the accurate modelling of discrete AGC controllers for interconnected power systems. Paper [9] clarifies about AGC using a method of distorted oppositional based gravitational search code optimised slip mode controller under restriction free environment. In paper [10], a work has been done for AGC of power system inter-connected through AC and DC tie-lines based on an adaptive fuzzy critic control. In Paper [11], an approach called as Ontology Driven Approach has been made to Generate Distributed Automation Control from Substation Automation Design. A recent work has been done on Distinct Detail AGC of Heated Water Systems under different time constants of the turbine with the different conditions in load of the power system. [12]. In paper [13], an attempt has been done on a connected scattered AGC of power system with active involvement of wind turbines across unknown dally communication network. In paper [14], recent study has been done on an Energy Storage System in a Wind Par in AGC.

In an ordinary power market, the process of generation, transmission and distribution is maintained and carried out by the vertically integrated utility (VIU), which supplies power to the customer at possible rates. But in the other hand, in an open area or market, generation companies (GENCOS) are independent and they may or may not involve in the AGC function. Distribution companies (DISCOS) combine with GENCOS for the power transfer to different regions. Therefore, in case of deregulated environment, the whole power system control is highly concentrated for balancing the frequency and tie line power flow deviations.

Many useful methods are introduced for AGC under this deregulated market to maintain frequency and power deviations stable in the power system such as modeling and comparing different controllers like integral (I), proportion integral (PI), proportion integral derivative (PID) and FUZZY logic controllers on AGC deregulated system with HVDC link [15].

In view of the above, the main aims of the work are to design AGC of a two area interlinked power system consisting of three sources i.e. hydel plant, a thermal plant and a diesel plant.

To optimize gains of IDDF controller by using LSA technique and to obtain active responses of the power system.
To observe the system's performance under deregulated environment and to establish the superiority of the IDDF controller over PID Controller.

2. Deregulation environment

Deregulation in electric industry plays a new role in this new environment which creates remarkable issues of entirely technical nature. Control of Frequency becomes a larger task when implemented on the basis of cost build operation and market operating demand. The primary necessity of the regulatory schemes is to enable competition between the power generators and the market conditions is created in the sector. The deregulated structure is made up of many GENCOs and DISCOs and each DISCO possessing contact with GENCOs in their own area or in another area. It is known as basically ''Bilateral Trading" and the execution process is done by ISO. The DISCO Participation Matrix (DPM) is employed to convey these different arrangements in matrix form. The number of rows and columns of DPM matrix represents the actual number of GENCOs and actual number of DISCOs present respectively. The entry in the DPM matrix is represented as contract participation factor (cpf) and it is defined as the ratio of each GENCOs involvement to net DISCO demand. The diagonal elements of the DPM matrix represent the local demand and off-diagonal elements represent the area wise contribution. The rows and columns of an AGPM is equal to the total number of GENCOs and DISCOs present in the whole power system, respectively. In general, cpf can be written as -

$$\sum_{i} \mathrm{cpf}_{ij} = 1.0 \tag{1}$$

Here CPF =contract participation factor.
In simulation, we have taken a two area AGC system under open market structure in which each area consists of a non- reheat thermal unit, a hydro unit and a diesel generating unit. Therefore, there proposed power system consists of six GENCOs, three in each area respectively the corresponding DPM will be.

$$\mathrm{DPM} = \begin{bmatrix} \mathrm{cpf}_{11} & \mathrm{cpf}_{21} & \mathrm{cpf}_{31} & \mathrm{cpf}_{41} \\ \mathrm{cpf}_{12} & \mathrm{cpf}_{22} & \mathrm{cpf}_{32} & \mathrm{cpf}_{42} \\ \mathrm{cpf}_{13} & \mathrm{cpf}_{23} & \mathrm{cpf}_{33} & \mathrm{cpf}_{43} \\ \mathrm{cpf}_{14} & \mathrm{cpf}_{24} & \mathrm{cpf}_{34} & \mathrm{cpf}_{44} \\ \mathrm{cpf}_{15} & \mathrm{cpf}_{25} & \mathrm{cpf}_{35} & \mathrm{cpf}_{45} \\ \mathrm{cpf}_{16} & \mathrm{cpf}_{26} & \mathrm{cpf}_{36} & \mathrm{cpf}_{46} \end{bmatrix} \tag{2}$$

3. System proposed

The proposed work consists of a two area interconnected power system consisting more than one generating sources in a particular area. Each area consists of a thermal generating source, a hydro generating source and a diesel generating source. Figure 1 shows the block diagram of the system's transfer function. The main objective of the AGC is to minimize the area control error (ACE).
Steady state power flow through the tie-line is given by:-

$\Delta P_{tie,12}^{scheduled} =$ (DISCOs Demand in area 1 to GENCOs in area 2)- (DISCOs Demand in area 2 to GENCOs in area 1) (3)

Mathematically (3) can be defined by

$$\Delta P_{tie,12}^{scheduled} = \sum_{k=1}^{3}\sum_{l=3}^{4} cpf_{kl}\Delta p_{LI} - \sum_{k=4}^{6}\sum_{l=1}^{2} cpf_{kl}\Delta p_{LI} \tag{4}$$

Actual tie-line power flow can be written as

$$\Delta P_{tie,12}^{actual} = \frac{2\Pi T_{12}}{s}(\Delta F_1 - \Delta F_2) \tag{5}$$

Error in the tie-line power is given below:

$$\Delta P_{tie,12}^{error} = \Delta P_{tie,12}^{actual} - \Delta P_{tie,12}^{scheduled} \tag{6}$$

$\Delta P_{tie,12}^{error}$ tends to zero in the steady state as the real tie-line power flow reaches the scheduled power flow.
The generation power produced by the GENCOs is described as:

$$\Delta p_{gk} = \sum_{l=1}^{4} cpf_{kl} P_{LI} \tag{7}$$

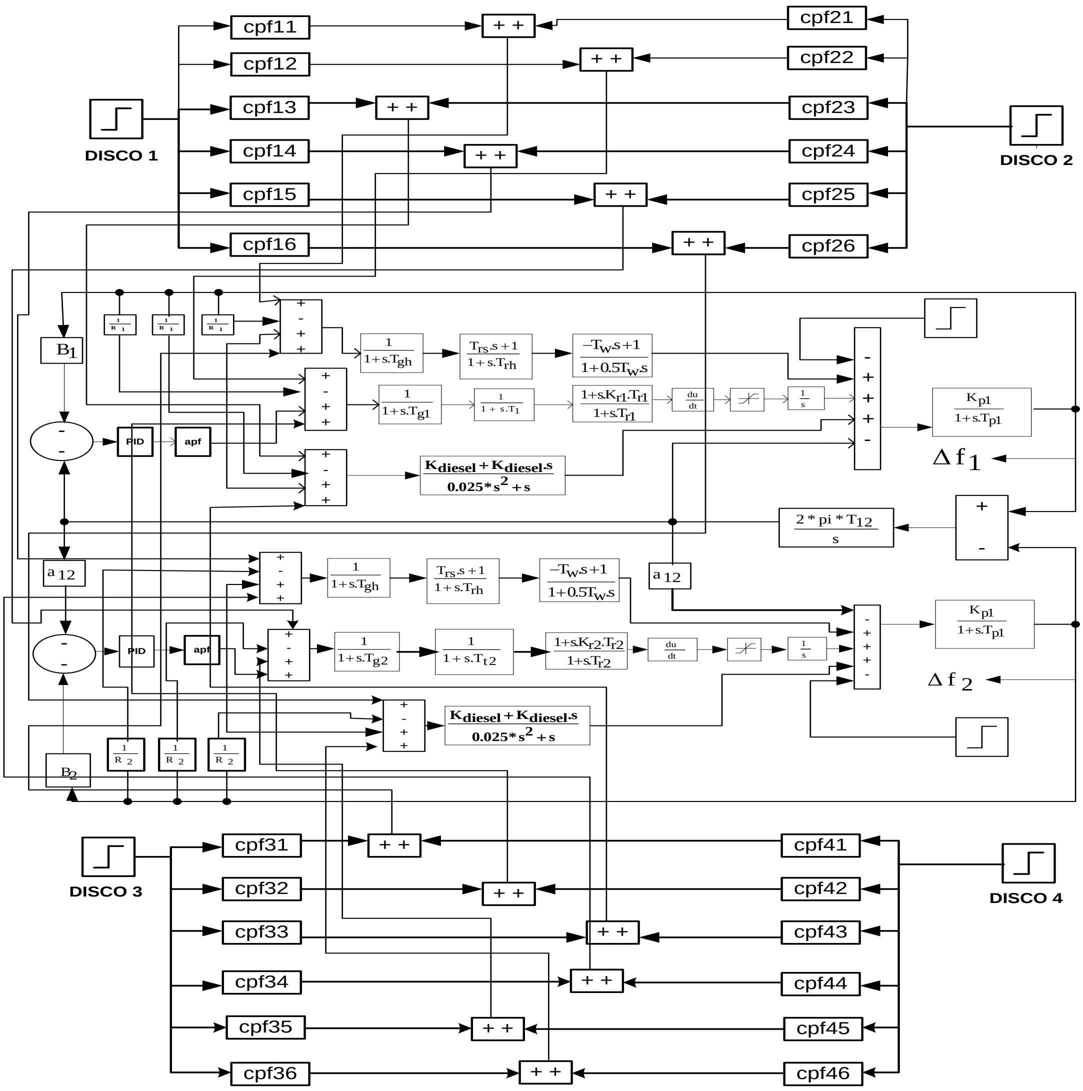

Fig. 1: Linearized Transfer Function Model of the Proposed System.

4. Controller proposed

4.1. PID control

Nowadays controller process techniques in the industry have changed a lot. We have studied various methods of controller such as adaptive control, fuzzy control etc. Proportional-integral-derivative (PID) controller is used for industrial purposes. The distinction between a desired set-point and a measured process variable is calculated as an error by a PID controller and a correction is applied based on proportional, integral and derivative terms, so the controller is called as PID.

In PID control the system parameters area constant and this act as the biggest disadvantage for a PID control. Improvement of the dynamic response and reduction of steady-state error can be achieved by using PID controller.

ROBUSTNESS:-

The main advantage of using PID controllers is its simple model and powerful performance in an open range of operating conditions. In case of high order, time delays, and nonlinearities, it is very difficult to find out the exact result by using PID controller. Constant stability and optimized PID values can be generated by using PID controllers.

PID controller transfer function is-

$$C(s) = K_p + \frac{K_i}{s} + K_d S \tag{8}$$

4.2. Integral double derivative controller

This paper proposes an integral double derivative controller acting as a secondary controller for the AGC of the entire system. As referred to in [16] the performance of the controller is more improved by using a double derivative. High frequency noises are attenuated by the presence of the derivative filter.

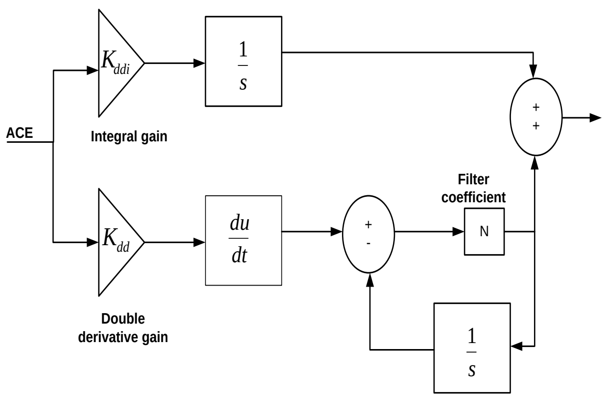

Fig. 2: The IDDF Controller.

The controller input is the error caused by the area (ACE) taken by the proposed controller. The control action can be denoted mathematically

$$U_i(s) = \left(\frac{K_i}{s} + K_{dd} s^2 \left(\frac{N}{s+N} \right) \times ACE_i \right) \quad (9)$$

Where K_i is the integral controller gain, K_{dd} denotes the derivative controller gain and N signifies the filter coefficient to attenuate the high frequency noises. These three gain parameters are optimised using a newly coined optimisation technique called the Lightning search optimization technique.

5. Optimization technique proposed

The process of Optimization is a new method of getting out the best solution. A completely advanced optimization technique was caused by lightning phenomena is proposed in this research work. LSA results provides better results in comparison to the other methods. In this paper lightning search algorithm (LSA) technique is used to solve constraint optimization problems.

It is an optimization technique followed by lightning phenomena which basically involves step leader propagation [16]. Lightning is a sudden electrostatic discharge that occurs due to thunder .During thunderstorm opposite polarity causes charge separation. So an electric field is created. Based on lightning phenomenon, the mechanism of step leader propagation known as projectiles are motivated form the concept of fast moving particles. Projectiles comprised of three types:

1) projectiles forming the first leader population of the step : they are mainly transition projectiles
2) Projectiles that attempt on becoming the leader, the space projectiles.
3) Projectile that indicates the best projectiles fired.

Projectiles represent the initial population. The projectile velocity is shown by.

$$V_s = \left[1 - \left(\frac{1}{\sqrt{1 - \left(\frac{v0}{c} \right)^2} - \left(sFr / mc^2 \right)} \right)^2 \right] \ldots \quad \ldots.. (10)$$

Where V0=initial velocity of the projectile
m=mass of the projectile
Fr=constant isolation rate
c=speed of the light
s=length of the path

The exploitation of the algorithm is maintained by the relative energy of the step leader.

Transition projectiles are emitted during random direction. These projectiles can be presented by random no of uniform probability distribution function. The equation is described below:-

$$f(a^T) = \begin{pmatrix} \frac{1}{y-x}; y \le x^T \le x \\ 0; a < x; a^T > y \end{pmatrix} \ldots\ldots \quad \ldots. (11)$$

Where x=lower boundaries.
y=upper boundaries. Random number of the student = a^T. N=Random projectiles

The position of the space projectile is determined by probability density function as:-

$$f(x^s) = \begin{Bmatrix} \frac{1}{\mu} e^{-x^{\frac{s}{\mu}}}; a \le x^T \le b \\ 0; x^s \le 0 \end{Bmatrix} \ldots \quad \ldots\ldots (12)$$

μ stands for the shaping parameter determining the space projectile location.

$P^s i$ is called the space projectile which can be represented as:

$$P^s i = Pi^s \pm e^{rand(\mu, i))} \quad 13)$$

Similarly the step leader needs to travel as near as to the ground and the energy of the projectile connected with it is the least. The statndard probability density function is described as.

$$f(x^L) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(x^l - \mu)^2} / 2\sigma^2 \quad (14)$$

The methodology can effectively be demonstrated using a flowchart.

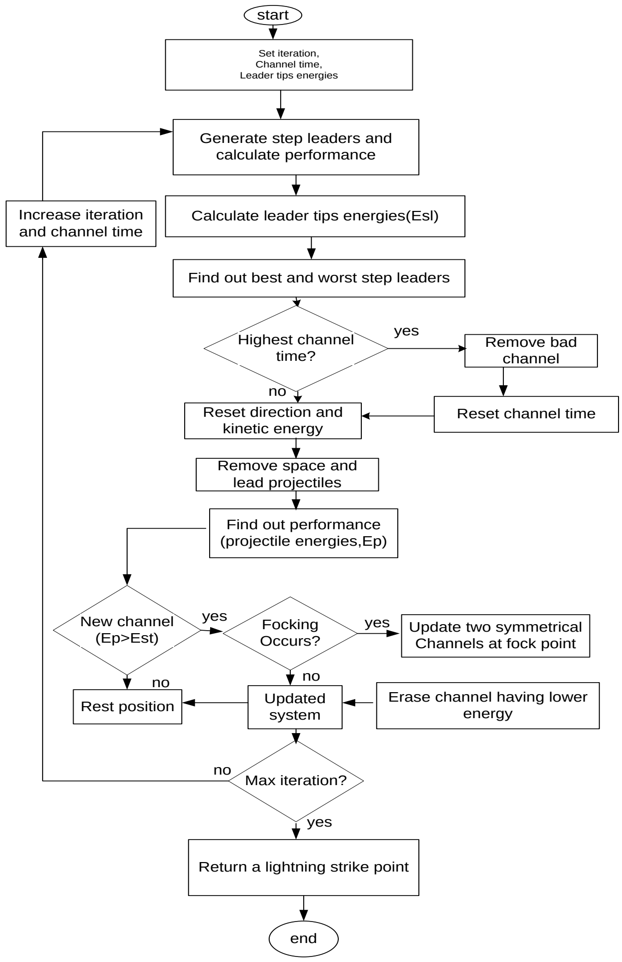

Fig 3: LSA Flowchart.

6. Results and analysis

The proposed two area hydro thermal system interconnected to each other is simulated in Matlab Simulink. The gains of the IDDF controller is solved with the help of a newly developed optimization technique called the Lightning search algorithm technique. Table 1 denotes the optimal gains of the IDDF controller tunes by LSA optimization technique.

Table 1: Optimum Controller Gains

PID	Kp1	Ki1	Kd1	Kp2	Ki2	Kd2
	0.3853	0.4907	0.3801	0.4476	0.4062	0.2080
IDDF	Kddi1	Kdd1	N1	Kddi2	Kdd2	N2
	0.1789	0.1538	350	0.3654	0.2147	300

The target function is considered as Integral time absolute error (ITAE).

$$J = \int_0^t \left(|\Delta f_1| + |\Delta f_2| + |\Delta p_{tie}| \right) dt \quad (14)$$

The entire system is simulated under two conditions:
Case 1: Base case

The analysis will be done subject to a Step Load Perturbation (SLP) of 0.01 pu in area 1. The load demand will be put forward only by DISCO1, DISCO2 and DISCO3. Assumption is made that the load demand by each DISCOs is 0.1 MW. The distribution participation matrix can be written as:

$$DPM = \begin{bmatrix} 0.3333 & 0.3333 & 0 & 0 \\ 0.3333 & 0.3333 & 0 & 0 \\ 0.3333 & 0.3333 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \quad (15)$$

The proposed model is simulated and the plots for the variation in frequency of area 1 (Δf_1), variation in frequency of area 2 (Δf_2) and the tie line power variation (Δp_{tie}) are observed

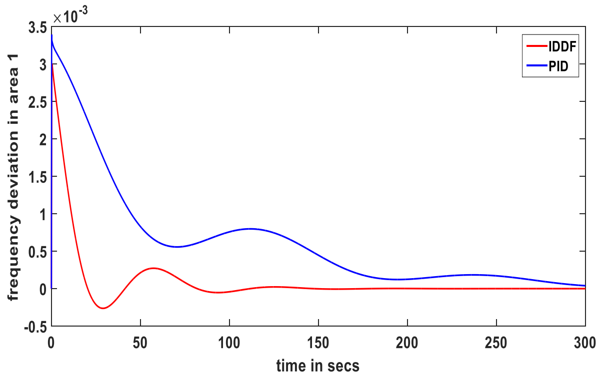

Fig. 4: Frequency Deviation in Area 1.

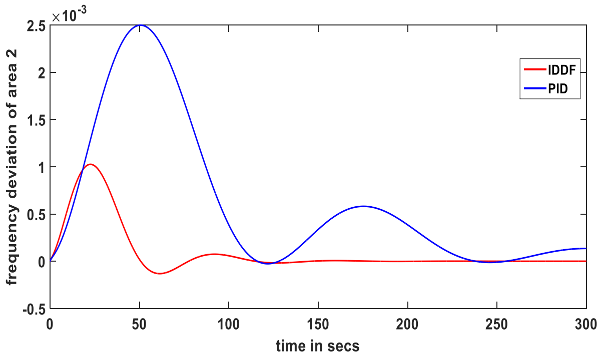

Fig. 5: Frequency Deviation in Area 2.

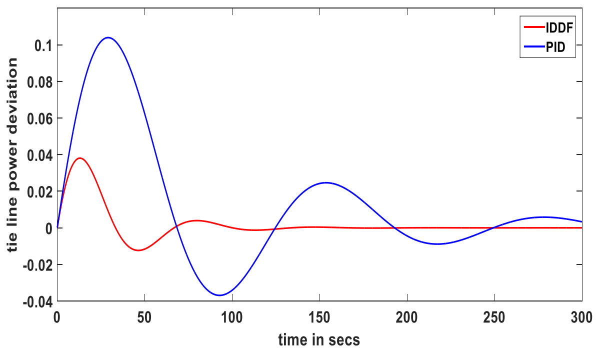

Fig. 6: Tie Line Power Deviation.

The above plots are found when the system was subjected to a step load perturbation of 0.01 pu. On the application of a random loading pattern, as depicted in Figure 7, the LSA optimized IDDF controller is found to have a better performance than the conventional PID controllers.

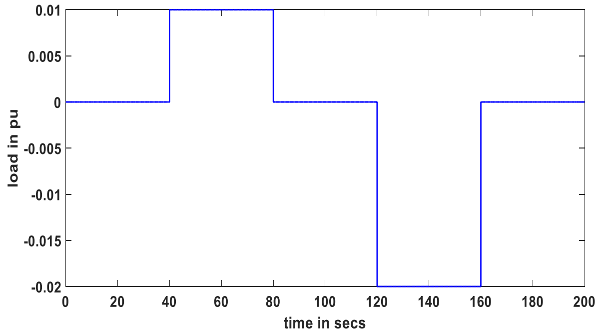

Fig. 7: Random Loading Pattern.

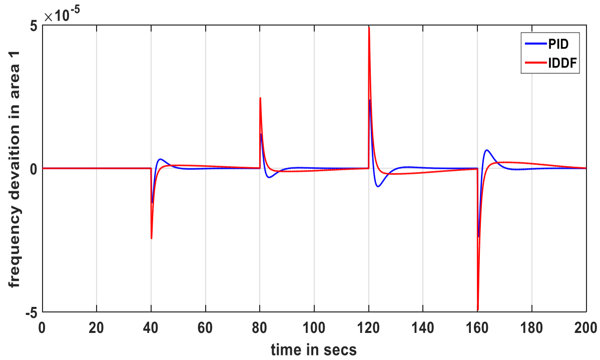

Fig. 8: Frequency Variation in Area 1.

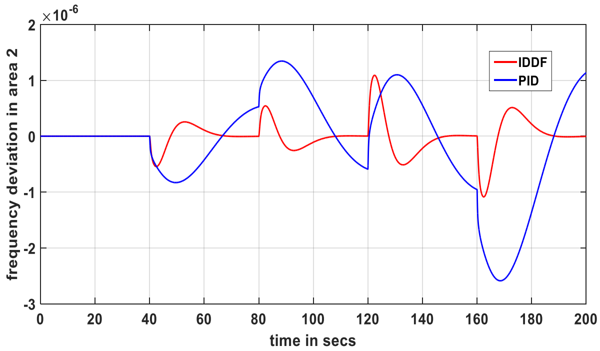

Fig. 9: Variation in Frequency of Area 2.

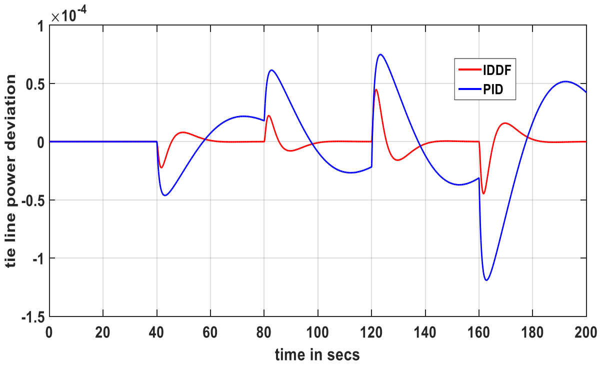

Fig. 10: Deviation in Tie Line Power Flow.

Case 2: Bilateral contract
The analysis of the system is extended to a bilateral market scenario where the DISCOs and the GENCOs come in contract with one another according to the proposed DPM.

$$\text{DPM} = \begin{bmatrix} 0.2 & 0.1 & 0.3 & 0 \\ 0.2 & 0.2 & 0.1 & 0.1666 \\ 0.1 & 0.3 & 0.1 & 0.1666 \\ 0.2 & 0.1 & 0.1 & 0.3666 \\ 0.2 & 0.2 & 0.2 & 0.1666 \\ 0.1 & 0.1 & 0.2 & 0.1666 \end{bmatrix} \quad 16)$$

The proposed model is simulated and the plots for the deviation in frequency of area 1 (Δf_1), deviation in frequency of area 2 (Δf_2) and the power flow deviation in the tie line (Δp_{tie}) are observed.

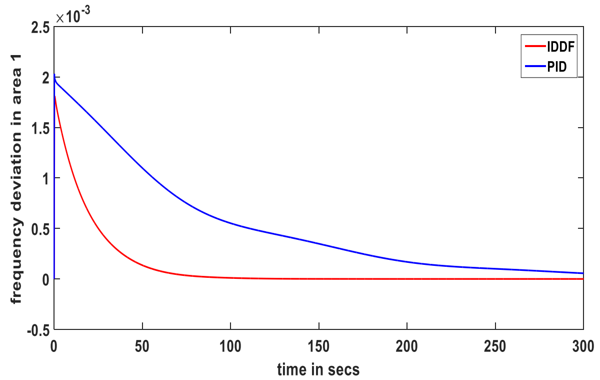

Fig. 11: Deviation in Frequency of Area 1.

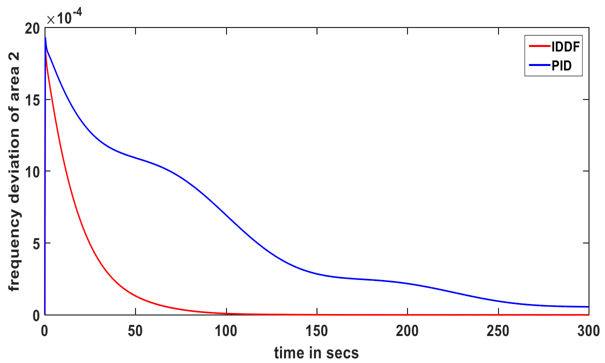

Fig. 12: Deviation in Frequency of Area 2.

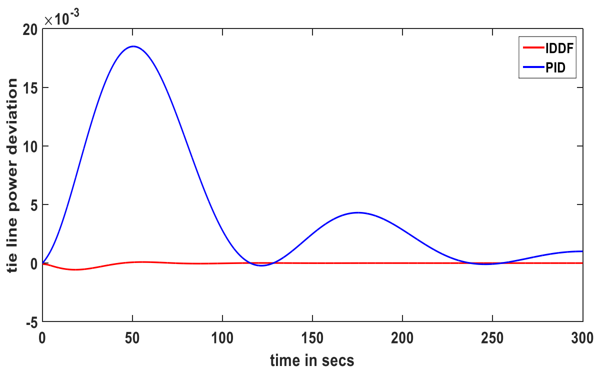

Fig. 13: Tie Line Power Deviation.

Case 3: Parameter variation

The analysis of the system is extended to parameter variation. The speed regulation factor (R) is set to a variation of + 25% and -25% and the system performance was observed. It can be seen that the LSA optimized IDDF controller was found to be much more effective in bringing the ACE to zero than the traditional PID controller.

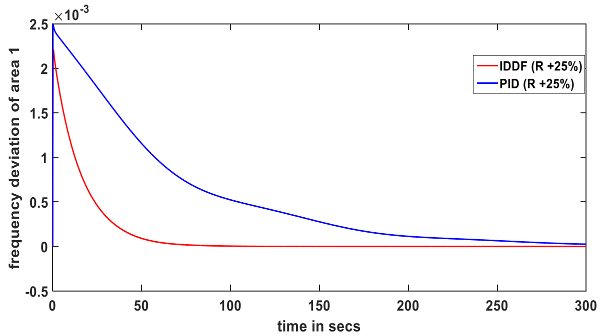

Fig. 14: Frequency Deviation in Area 1.

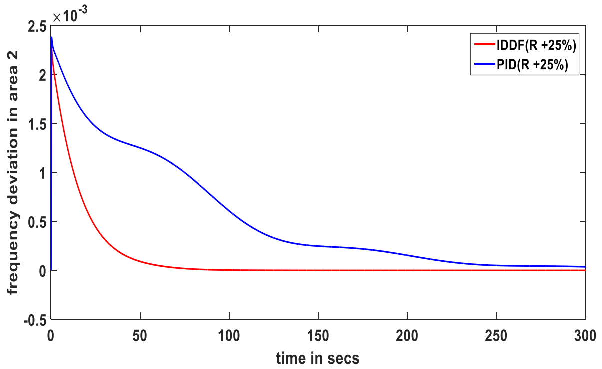

Fig. 15: Deviation in Frequency of Area 2.

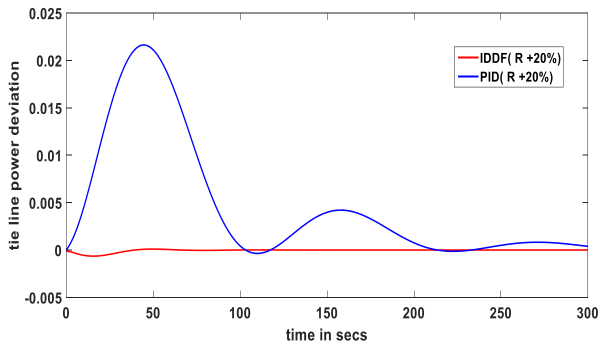

Fig. 16: Deviation in Tie Line Power.

The following are the plots for a change of speed regulation factor to -25%.

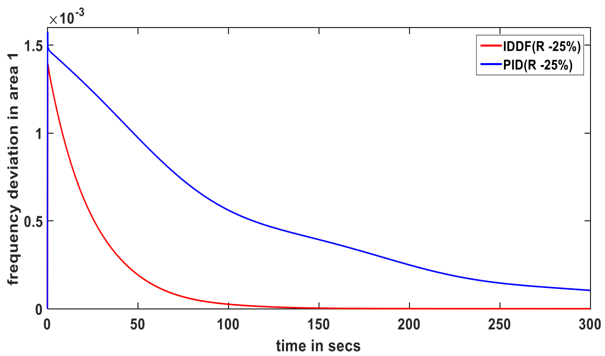

Fig. 17: Deviation in Frequency of Area 1.

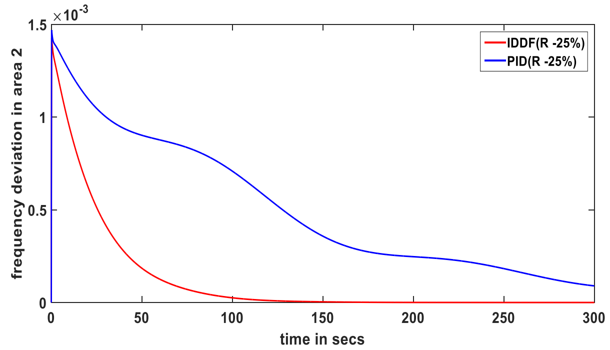

Fig. 18: Deviation in Frequency of Area 2.

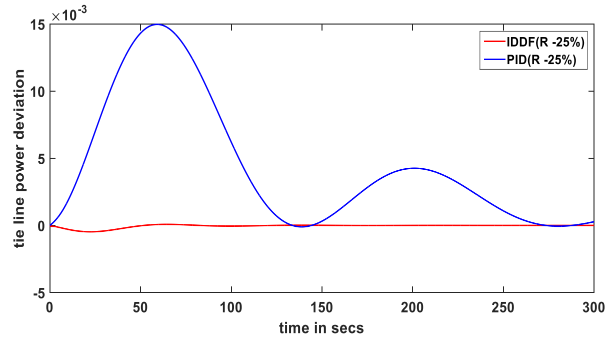

Fig. 19: Deviation in Tie Line Power.

The above results clearly establish the superiority of the LSA optimized IDDF controller over the traditional PID controller. The extended analysis for parametric variations clearly depicts the effectiveness of the proposed controller under restructured scenario.

7. Conclusion

In this project we have designed a controller having both integral and derivative part which is acting as a secondary controller for the AGC of the proposed two area power system. The gains of the IDDF controller are tuned with the help of a newly proposed Lightning search algorithm (LSA). In this case, the objective function is taken as The integral time absolute error (ITAE). The system has been simulated under two market scenarios: the base case and the bilateral contract subject under two disturbance conditions: the step load perturbation of 0.01 pu and the random load change both being applied to area 1 respectively. The proposed IDDF controller is effective to minimize the frequency deviations in both are1 and 2 and it also reduces deviations in frequency and the power deviations in the tie-line in lesser time span as compared to the PID controllers. So the supremacy of the proposed controller has been established.

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