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PID Controller Based AGC under Two Area Deregulated Power System

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Abstract — In this paper, AGC of deregulated system is analyzed with the use of conventional controllers. Mainly, these controllers are considered for the analysis of AGC of two area interconnected system through a tie line for frequency control, area control error and tie line power control. The concept of DISCO participation matrix is introduced and reflected in the two-area diagram to make the visualization of contract easier. Initially, PI controller is designed for the system under consideration than PI controller is replaced PID controller to obtain better and reliable control. Dynamic performance of two area restructured power system is simulated and observed in terms of system parameters like frequency, area control error and tie line power control 0.01 percent step load change. Simulation is carried out in MATLAB 7.1.

Index Terms — Automatic Generation Control, PI, PID, Load Frequency Control, Deregulation, DISCO, GENCO, TRANSCO.

1 INTRODUCTION

THE deregulated power system structure changed in such a way that would allow the evolving of more specialized industries for generation (GENCO), transmission (TRANSCO) and distribution (DISCO). In the restructured power system, DISCOs in each area can contract with GENCOs in its own or other areas. As there are several GENCOS and DISCOS in the restructured power system, a DISCO has the freedom to have a contract with any GENCO for transaction of power. Such transactions are called bilateral transactions. All the transactions have to be cleared through an impartial entity called an independent system operator (ISO). The ISO has to control a number of so-called ancillary services, one of which is load frequency control. There is some difference between the AGC operation in conventional and deregulation environment. After deregulation, optimization and operation are changed but their basic idea for AGC is kept same. In the new environment, DISCOs may contract power from any GENCOs and independent system operator has to supervise these contracts. DISCO participation matrix (DPM) concept is taken to understand the several contracts that are implemented by the GENCOs and DISCOs [10].

2 RESTRUCTURED SYSTEM

In a power system main aim of AGC is to achieve zero static frequency error and to distribute generation among areas so that an interconnected tie line flow matches the prescribed schedule and moreover it balance total generation against total load and tie line power exchanges [1]. A load frequency control is designed in power system should be able to provide the acceptable levels of power quality by keeping the frequency, voltage magnitude within tolerable limits of system. Changes in the power system load affect mainly the system change in frequency. So the control of the real power in the power system is dealt separately. The load frequency control mainly deals with the control of the system frequency [2]. For 100 years, a power system regulated industry in one area only have one company or government agency that generation, transmission and distribution and its services are provided to customers. But in 90's the concept of deregulation is introduced to encourage competition and beneficial for customers. Vertically integrated utilities no longer exist. The utilities no longer own generation, transmission, and distribution instead, there are three different entities GENCOs (generation companies), TRANSCOs (transmission companies) and DISCOs (distribution companies). As there are several GENCOs and DISCOs in the deregulated structure, a DISCO has the freedom to have a contract with any GENCO for transaction of power. A DISCO may have a contract with a GENCO in another control area.

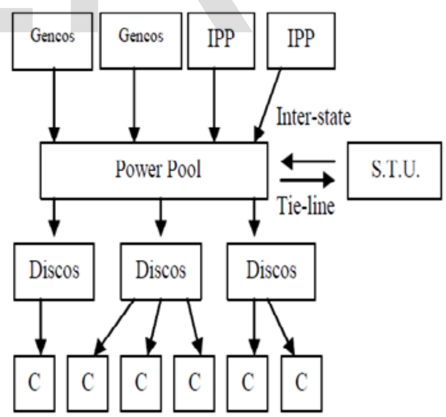

Figure 1: Structure of Deregulated System

Such transactions are called bilateral transactions [6]. All the transactions have to be cleared through an impartial entity called an independent system operator (ISO). The ISO has to control a number of so-called ancillary services one of which is AGC. The structure of deregulated system is shown in Figure 1. Deregulation Process of removing restrictions and regulations to achieve competitive wholesale prices without compromising adequacy, system reliability and security unbundling of traditionally vertically integrated utility. One of the principal characteristics of a competitive structure is the identification and separation of the various tasks which are normally carried out within the traditional organization so that these tasks can be open to competition whenever practical and

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profitable. This process is called unbundling [7]. An unbundled structure mainly deals to minimize the total costs of operating the utility.

3 DISCO PARTICIPATION MATRIX

In the restructured environment, GENCOs sell power to various DISCOs at normal range prices. So, DISCOs have the liberty to choose the GENCOs for contracts. They can or cannot have contracts with the GENCOs in their own area [12]. This makes various additions of GENCO-DISCO contracts possible in practice. Concept of a "DISCO participation matrix" (DPM) make the visualization of contracts in an easy way. DPM is a matrix with the number of rows equal to the number of GENCOs in a particular system and the number of columns equal to the number of DISCOs in the system [17]. Each entry in this matrix can be thought of as a fraction of a total load contracted by a DISCO (column) toward a GENCO (row). Thus, the entry corresponds to the fraction of the total load power contracted by DISCO from a GENCO. The sum of all the entries in a column in this matrix is unity. DPM shows the participation of a DISCO in a contract with a GENCO, hence the name DISCO participation matrix. Two-area system in which each area has two GENCOs and two DISCOs is considered. Let GENCO1, GENCO2, DISCO1, and DISCO2 be in area 1 and GENCO3, GENCO3, DISCO4, and DISCO4 be in area 2 as shown in Figure 2.

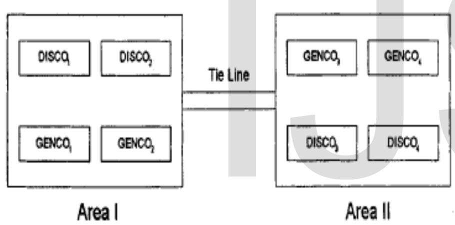

Figure 2: Two Area Interconnected Power System in Restructured System

It is assumed that each DISCO demands 0.1 MW power from GENCOs as defined by cpfs in DPM matrix and each GENCO participates in AGC as defined by following apfs are given below:

apf1 = 0.75
apf2 = 1 – apf2 = 0.25
apf3 = 0.5
apf4 = 1 – apf3 = 0.5

The off diagonal blocks of the DPM correspond to the contract of a DISCO in one area with a GENCO in another area. The scheduled power on the tie line in the direction from area 1 to area 2 is given below:

Hence

$$\Delta P_{tie12,\,scheduled} = -\,0.05 \text{ pu MW}$$

It is to be observed that it settles to -0.05 pu MW, which is the scheduled power on the tie line in the steady state. In the steady state, the GENCOs must generate:

$$\Delta P_{M1} = 0.5(0.1) + 0.25(0.1) + 0 + 0.3(0.1)$$
$$= 0.105 \text{ pu MW}$$
$$\Delta P_{M2} = 0.045 \text{ pu MW}$$
$$\Delta P_{M3} = 0.195 \text{ pu MW}$$
$$\Delta P_{M4} = 0.055 \text{ pu MW}$$

where

DPM – Disco participation matrix
cpfij – Contract participation matrix of j-th GENCO in i-th area
apf – ACE participation factor
ΔPLj – Total demand of DISCO j
$\Delta P_{tie12,scheduled}$ – Scheduled tie line power flow at steady state in case of area 2.

Above, shows actual generated powers of the GENCOs. The trajectories reach respective desired generations in the steady state.

4 MODEL OF DEREGULATED SYSTEM

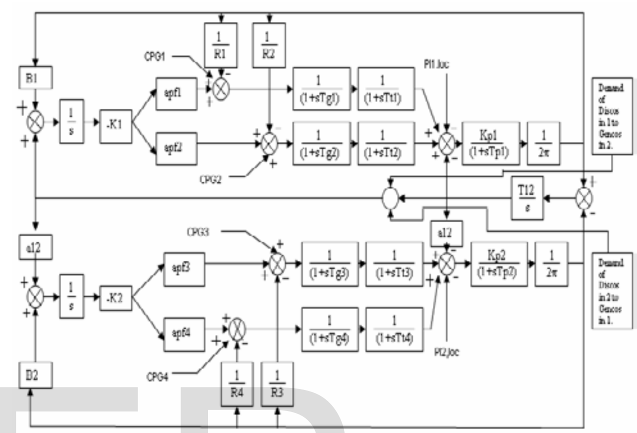

Figure 3: Block Diagram of Deregulated System

Whenever a load demanded by a DISCO changes, it is reflected in a local load in the area to which this particular DISCO belongs. This corresponds to the local loads ΔPL1 and ΔPL2 and should be reflected in the deregulated AGC system block diagram at the point of input to the power system block. As there are many GENCOs in each area, ACE signal has to be distributed among them in proportion to their participation in the automatic generation control. Coefficients that distribute ACE to several GENCOs are termed as ACE participation factors (apfs). As like, the traditional AGC system in which a DISCO demands a particular GENCO or GENCOs for load power. So, as a particular set of GENCOs are supposed to follow the load demanded by a DISCO, information signals must flow from a DISCO to a particular GENCO specifying corresponding demands. The demands are specified by Contract Participation Factor (elements of DPM) and the pu MW load of a DISCO. These signals carry information as to which GENCO has to follow a load demanded by DISCO. The scheduled steady state power flow on the tie line is given as

$\Delta P_{tie1\text{-}2,scheduled}$ = (demand of DISCOs in area 2 from GENCOs in area 1) - (demand of DISCOs in area 1 from GENCOs in area 2)

$$\Delta P_{tie12,error} = \Delta P_{tie12,actual} - \Delta P_{tie12,scheduled} \quad (1)$$

$\Delta P_{tie12,error}$ vanishes in the steady state as the actual tie line power flow reaches the scheduled power flow. This error signal is used to generate the respective ACE signals as in the traditional scenario:

$$ACE_1 = B_1 \Delta f_1 + \Delta P_{tie12,error}$$

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(2)

$ACE_2 = B_2\Delta f_2 + \Delta P_{tie21,error}$

(3)

Where

$\Delta P_{tie12,error} = -(Pr_1/Pr_2)\Delta P_{tie12,error}$

(4)

P_{r1} - Rated power of area 1
P_{r2} - Rated power of area 2

Therefore

$ACE_1 = B_1\Delta f_1 + \alpha_{12}\Delta P_{tie12,error}$

(5)

Where me, the tie line power error, $\Delta P_{tie1\text{-}2,error}$ is defined as
$\alpha_{12} = - P_{r1} / P_{r2}$ = Participation constant
$\Delta P_{tie12,scheduled}$ – Scheduled steady state power flow on a tie line
$\Delta P_{tie12,error}$ – Tie line power error at a given time
$\Delta P_{tie12,actual}$ - Actual tie line power flow
ACE_1 – Area control error in area 1
ACE_2 – Area control error in area 2
B_1 – Area frequency bias of area 1
B_2 – Area frequency bias of area 2
Δf_1 – Change in frequency in area 1
Δf_2 – Change in frequency in area 2
P_{r1} – Rated power of area 1
P_{r2} – Rated power of area 2
$\Delta P_{L1,LOC}$ – Local load in area 1
$\Delta P_{L2,LOC}$ – Local load in area 2

The block diagram for AGC in a deregulated system is shown in Figure 3. The local loads in area 1 and 2 are denoted by $\Delta P_{L1,Loc}$ and $\Delta P_{L2,Loc}$ respectively.

5 TECHNIQUES

5.1 PI Controller

The combination of proportional and integral terms is important to increase the speed of the response and also to eliminate the steady state error. In practical examples, use PI controller for the system ability to reduce the error up to maximum value. K_p and K_i are the tuning knobs, are adjusted to obtain the desired output. When there is load perturbation in the LFC it will result to a steady state frequency deviation. The essence of the supplementary control action is to reduce the frequency deviation to zero. The integral controller applied at the load reference setting, changes the speed set point. The controller actually increases the system type by 1 which forces the final frequency deviation to zero. The integral controller is adjusted for a satisfactory of system response.

PI controllers are the most often type used today in industry, a control without the mode is used when fast response of the system is not required large disturbances and noise are present during operation of the process there is only one energy storage in process (capacitive or inductive). There are large transport delays in the system. Transfer function of PI controller is given below.

$$K_p + K_i / S$$

Where

K_p - Proportional Gain
K_i - Integral Gain

PI controller have unique ability that they can return the controller variable back to exact set point following a disturbance that's why these are known as reset controllers. This controller helps in reducing the steady state error, thus makes the system more stable and even slow response of the over damped system can be made faster with the help of these controllers. Simulink Modeling of Restructured System with PI Controller in restructured system is given below in figure 7.

5.2 PID CONTROLLER

A proportional integral derivative controller (PID controller) is a control loop feedback mechanism (controller) widely used in industrial control systems [13]. A PID controller calculates an error value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error by adjusting the process through use of a manipulated variable. There are several methods for tuning a PID loop. The most effective methods generally involve the development of some form of process model, and then choosing P, I, and D based on the dynamic model parameters. The Ki and Kd gains are first set to zero. The proportional gain is increased until it reaches the ultimate gain, Ku, at which the output of the loop starts to oscillate. The PID controller encapsulates three of the most important controller structures in a single package. The parallel form of a PID controller has transfer function.

$$C(S) = K_p + K_i / S + K_d.S$$
$$= K_p\,(1 + 1 / T_i S + T_d.S)$$

K_p - Proportional Gain
K_i - Integral Gain
T_i - Reset Time - Kp / Ki
K_d - Derivative gain
T_d - Rate time or derivative time

Tuning Using Ziegler-Nichols Method of PID Controller

Ziegler-Nichols formulae for specifying the controllers are based on plant step responses. The Ziegler-Nichols closed loop method is based on experiments executed on an established control loop [14]. Main purpose of tuning the controller is to provide a constant output at a specified set point. Firstly before starting the procedure of tuning analyze offset from set point "error" with Instantaneous offset (proportional), Permanent offset (integral), Change in offset (derivative). PID tuning is done with ultimate gain (Ku) and ultimate period (Tu). We need to use a table to find these K_p, K_d, K_i gain parameters value by substituting Ku, Tu values. Table shown below is used to form K_p, K_d, K_i for quarter amplitude decay.

TABLE 1

SET GAIN PARAMETERS ACCORDING TO ZEIGLER NICHOLS METHOD

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Design a PID controller using Z-N method closed loop method. Figure 4 shows the closed loop response of any G(S) transfer function whose PID controller is to be designed.

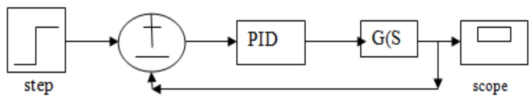

Figure 4: Closed Loop Response of any G(S) System

With the use of following steps we can find easy way for tuning the PID controller by finding the gain parameters with the use of Z-N method.

- Assume $K_i = 0$ and $K_d = 0$
- Find transfer function from the closed loop response of the system. Critical equation with C_k equation is obtained.
- Using Routh criteria we can calculate the Kcritical from critical equation.
- Using even equation, substitute with Kcritical using complex domain to find Wcritical.
- Find T_u.
- Then with the $K_{critical}$ we can easily define K_u.
- Find K_i, K_d, K_p, by substituting all the values in given the Table 1.

So, from the control equation we obtain the proportional, integral and derivative scaling coefficients. If the response is not stable then increase the value of K_c until sustained oscillations is observed in system output. The obtained values of gain parameters are given below.egin with a title and are followed by the text, in italics.

TABLE 2
GAIN PARAMETERS

PARAMETERS	***PI***	***PID***
K_i	0.09	0.6
K_p	0.8	1.7443
K_d	0	0.0515955

The deregulated system performance with PI controller is taken in three parameters that is frequency, area control error and tie line power of the two area interconnected system.

6 SIMULATION AND RESULTS

6.1 SIMULATION WORK DONE

In simulation diagrams shown below, are the two-area system in the deregulated case with identical areas can be controlled with controllers with respect to system parameters to obtain the best

Controller	***K_p***	***K_i***	***K_d***
P	0.5 Ku	-	-
PI	0.45 Ku	0.54 Ku/Tu	-
PID	0.6 Ku	1.2 Ku/Tu	0.6 Ku.Tu/8

response. Each system has individual controller response on the system which is estimated by three parameters they are frequency, tie line power and area control error. Initially, the PI controller is set in the system to remove the error in the system and its indi vidual response to the system is given below in figures.

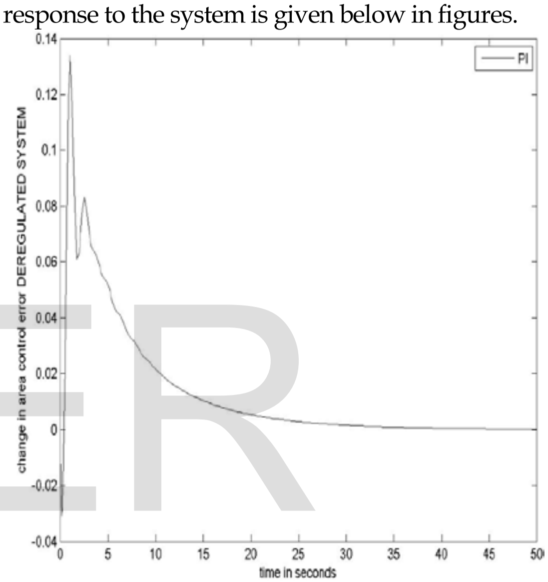

Figure 5 Area Control Error Response in Deregulated System

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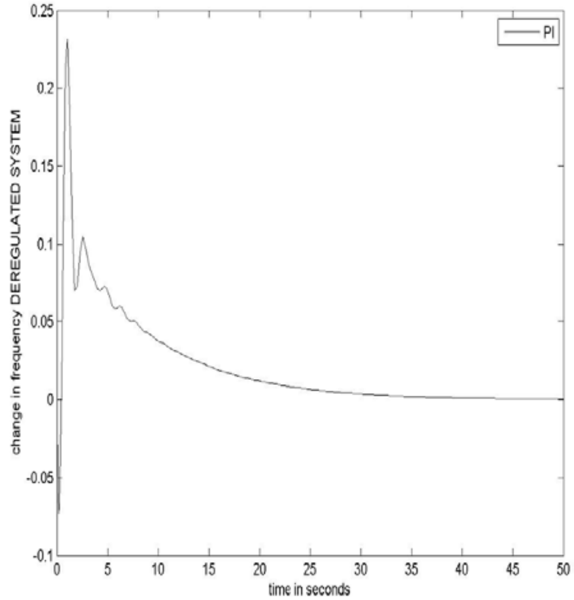

Figure 6: Frequency Response in Deregulation System

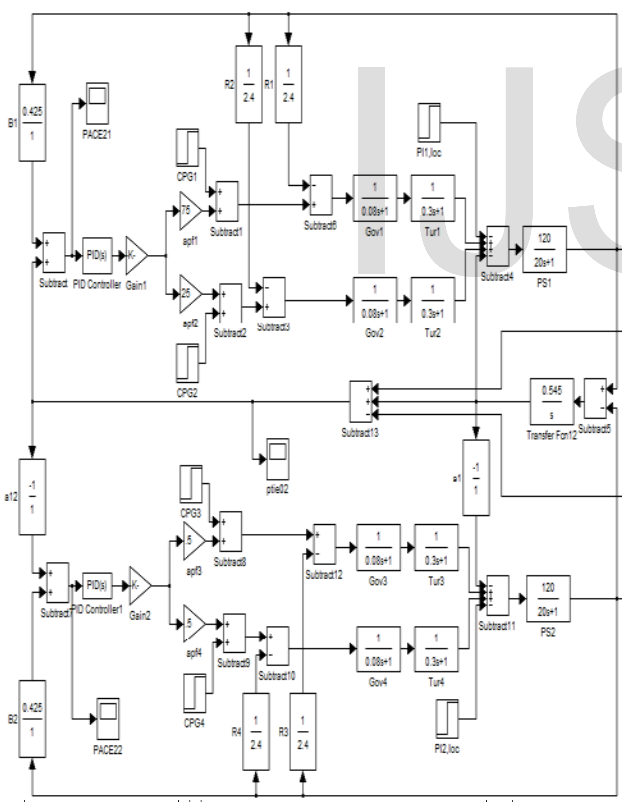

Figure 7: Deregulated System with PI Controller

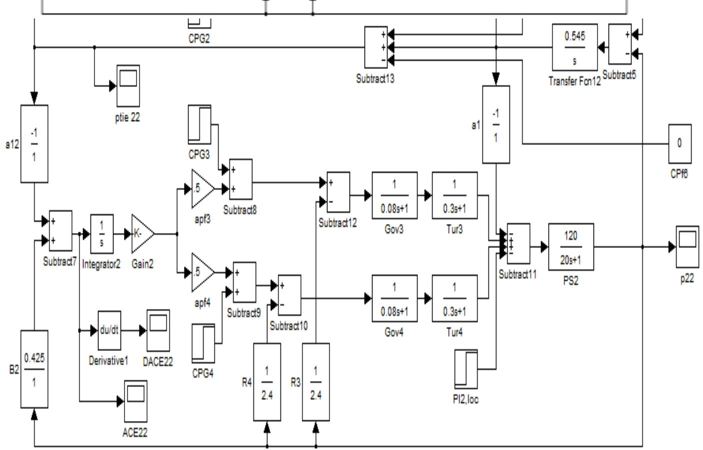

Figure 8: Deregulated System with PID Controller

Secondly, the PID controller is set in the system to remove the error in the system and its individual response to the system is given below in figures.

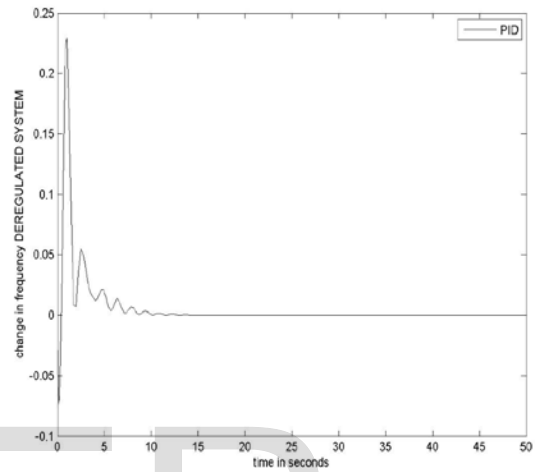

Figure 9: Frequency Response in Deregulated System

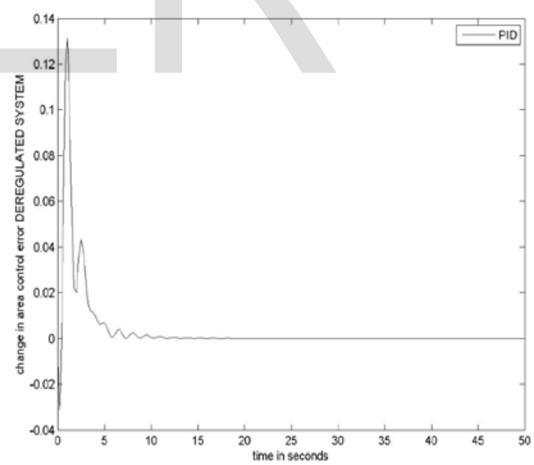

Figure 10: Area Control Error in Deregulated System

Simulation is performed for two area interconnected power system of deregulated system with two different conventional controllers i.e. PI and PID. Using MATLAB 7.1 and the system performance is observed Δf1, Δf2, ΔPtie, ΔACE1 and ΔACE2 for the step load change in two area interconnected system. For the sake of comparison and analyzing the performance of PI and PID controller responses of similar entities have been obtained on same graph.

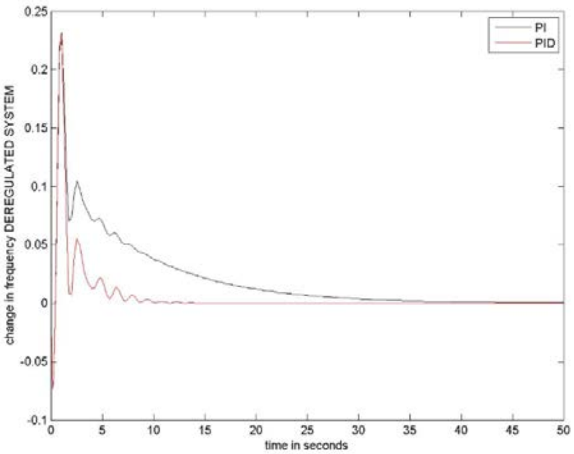

Figure 11: Change in Frequency in Deregulated System in Area 1

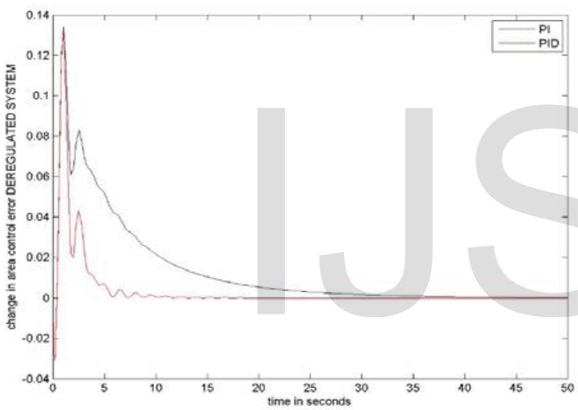

Figure 12: Change in Area Control Error in Deregulated System in Area 1

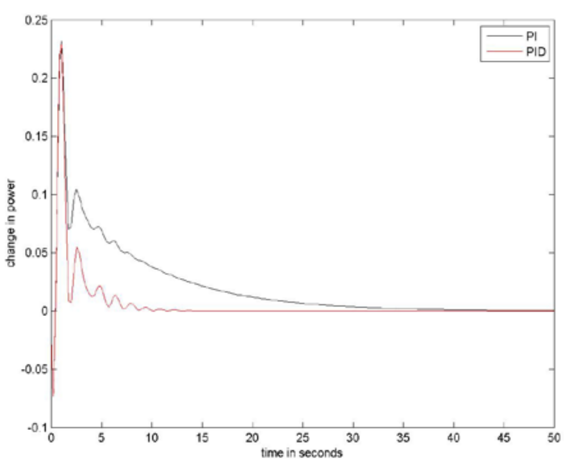

Figure 13: Change in Tie Line Power in Deregulated System

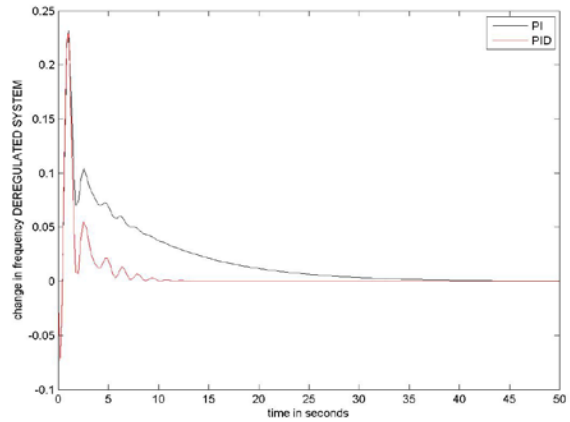

Figure 14: Change in Frequency in Deregulated System in Area 2

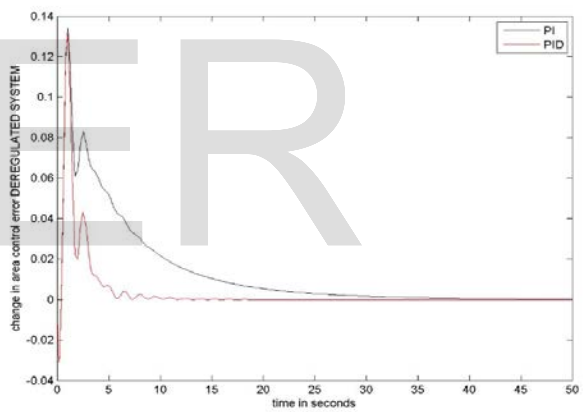

Figure 15: Change in Area Control Error in deregulated System in Area 2

6.2 RESULT TABLES

TABLE 3
COMPARISON OF CHANGE IN FREQUENCY WITH PI AND PID CONTROLLER OF AREA 1

	With PI	***With PID***
Maximum Overshoot	**0.225**	**0.23**
Minimum Overshoot	**0**	**-0.07**
Settling Time (in sec)	**25.5**	**10.9**

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TABLE 4
COMPARISON OF ΔACE WITH PI AND PID CONTROLLER OF AREA 1

	With PI	*With PID*
Maximum Overshoot	**0.137**	**0.135**
Minimum Overshoot	**0**	**-0.03**
Settling Time (in sec)	**25.4**	**10.5**

TABLE 5
COMPARISON OF ΔPTIE WITH PI AND PID CONTROLLER

	With PI	*With PID*
Maximum Overshoot	**0.235**	**0.225**
Minimum Overshoot	**0**	**-0.065**
Settling Time (in sec)	**25.9**	**10.8**

TABLE 6
COMPARISON OF CHANGE IN FREQUENCY WITH PI AND PID CONTROLLER OF AREA 2

	With PI	*With PID*
Maximum Overshoot	**0.225**	**0.23**
Minimum Overshoot	**0**	**-0.07**
Settling Time (in sec)	**25.5**	**10.9**

TABLE 7
COMPARISON OF ΔACE WITH PI AND PID CONTROLLER OF AREA 2

	With PI	*With PID*
Maximum Overshoot	**0.137**	**0.135**
Minimum Overshoot	**0**	**-0.03**
Settling Time (in sec)	**25.4**	**10.5**

The result shown above in tabular form are the comparison of each parameter in deregulated system. The parameters compared one by one are change in frequency, change in area control error and change in tie line power of the system with PI and PID controller. Comparison graphs shows that among PI and PID controllers the PID controller response in terms of transient nature and reduced settling time, maximum and minimum overshoot is better. This clarifies that the for better dynamic responses using PID controller with deregulated system the dynamic performance of system is improved and provides better stability to the system.

7 Conclusion

In this paper, a power system model is proposed to analyze the dynamic performance of AGC of two area interconnected power system of deregulated system with the use of PID controller. It gives an overview of Automatic Generation Control in deregulated environment which acquires a fundamental role to enable power exchanges and to provide better response for the electricity trading. The AGC is treated as an ancillary service essential for maintaining the electrical system reliability at a satisfactory level. The important role of AGC will continue in restructured electricity markets, but with amendments. Bilateral contracts can exist between DISCOs in one control area and GENCOs in other control areas. The use of a DISCO Participation Matrix facilitates the simulation of bilateral contracts. It is emphasized that the new challenges will require some amendments in the current AGC strategies to satisfy the needs of the different market organizations and the specific characteristics of each power system.

A PID controller is designed and its feasibility is studied by varying system parameters. It has been observed that responses of the system with PID controller gives better results in terms of dynamic parameters such as peak overshoot and settling time. PID gives better response by reducing settling time. The ability of two area interconnected power system of PID controller is improved as the settling time is reduced in PID as compared to PI. When compared with PI controller than PID controller of deregulated power system gives more rapidly and responsive results. Effectiveness of PID controller with the deregulated system is used to improve the stability of the system. Simulation results presented justify the connection of PID controller in deregulated system for stable and quality power. From the results, it has been concluded that

- The response of deregulated system with PID controller gives better performance than the PI controller in the two identical area interconnected power system.
- The response is much improved when identical area interconnected power system is done with restructured system with PID controller on the basis of settling time.

- The response with PID controller of deregulated system is better on the basis of maximum and minimum overshoot.

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REFERENCES

[1] Donde V. and Pai M.A, "Simulation and Optimization in an AGC System after Deregulation", *IEEE Transactions on Power Systems, Vol. 16, Issue 3 pp. 481-489 2001*.

[2] Garg I. and Ilyas M , "Study of Two Area Load Frequency Control in Deregulated Power System", *International Journal of Innovative Technology and Exploring Engineering (IJITEE), Vol. 1, Issue 2, ISSN: 2278- 3075 pp. 42-45 2012*.

[3] Ibraheem, Naimul H., and Hussein A.A,"Decentralized Automatic Genenration Control of Interconnected Power System Corporating Asynchronous tie lines", *A Springer Open Journal Issue 3 pp.1-8 2014*.

[4] Ikhe A. and Kulkarni A , "Load Frequency Control for Two Area Power System Using Different Controllers", *International journal of advances in engineering and technology, ISSN 2231-1963 pp.1796-1802 2013*.

[5] Kothari D.P. and Nagrath I.J.,"Modern Power System Analysis", *Fourth Edition, Third reprint, Tata McGraw Hill Education Private Limited pp. 320 -350 2012*.

[6] Kumar A., Singh S.,"Automatic Generation Control Issues in Power System Operation after Deregulation Review", *International Journal of Advanced Research in Computer Science and Software Engineering Vol. 4, Issue 5, ISSN: 2277 128X pp.705-710 2014*.

[7] [7] Kumar P., Akazmi S. and Yasmeen N.,"Comparative Study of Automatic Generation Control in Traditional and Deregulated Power Environment", *World Journal of Modeling and Simulation Vol. 6, No. 3, pp. 189-197, ISSN 1746-7233 pp.189-197 2010*.

[8] Kumar S.R., Ganapathy S., "Artificial Cooperative Search Algorithm Based Load Frequency Control of Deregulated Power System with SMES Unit" *Journal of Theoretical and Applied Information Technology. Vol. 63, Issue 1, ISSN: 1992-8645 pp.20-29 May 2014*.

[9] Meliopoulos A.P.S., Cokkinides G.J. and Bakirtzis A.Z., "Load-Frequency Control Service in a Deregulated Environment" *Decision Support Systems, Elsevier, pp. 243–250 1999*.

[10] Mishra A. and Behera M.,"Simulation and Modeling of Automatic Generation Control using PI and PID Controller in Deregulated Environment", *International Journal of Computer Applications International Conference on Emergent Trends in Computing and Communication (ETCC), pp. 0975 – 8887 2014*.

[11] Mukta and Surjan B.S., "Load Frequency Control of Interconnected Power System In Deregulated Environment: A Literature Review", *International Journal of Engineering and Advanced Technology (IJEAT), Vol. 2, Issue 3, ISSN: 2249 – 8958 pp. 431-445 2013*.

[12] Nain P., Singh K.P. and Singh A.K., "Automatic Generation Control of an Interconnected Power System Before and after Deregulation", *International Journal of Computer Applications (0975 – 8887) Vol. 61 Issue 15 pp. 11-16 2013*.

[13] Pandey S.K., Mohanty S.R., and Kishore N.,"A Literature Survey on load Frequency Control for Conventional and Distribution generation Power System", *Renewable and Sustaible Energy Reviews, Vol. 25, pp. 318-334 2013*.

[14] Pandey S.K., Singh S.P., and Singh V.P., "Load Frequency Control of an Asynchronous Restructured Power System: A Fuzzy Logic Approach" *International Journal of Engineering, Science and Technology Vol. 4, Issue 1, pp. 16-22 2012*.

[15] Prakash S. and Sinha S.K., "Application Of Artificial Intelligence In Load Frequency Control of Interconnected Power System" *International Journal of Engineering, Science and Technology Vol. 3, Issue 4, pp. 264-275 2011*.

[16] Rajalakshmi L., Suganyadevi M.V., Parameswari S., "Congestion Management in Deregulated Power System by Locating Series FACTS Devices", *International Journal of Computer Applications (0975 – 8887) Vol. 13 Issue 8 2011*.

[17] Rakhshani E. and Sadeh J., "Load Frequency Control of Multi-Area Restructured Power System", *IEEE POWER INDIA CONFERENCE & POWERCON NEW DELHI, INDIA 2008*.

[18] Salgotra A. and Verma S.,"Modeling and Simulation of Automatic Generation Control in a Deregulated Environment and its Optimization LQR Based Integral Controller", *International Journal of Emerging Technology and Advanced Engineering, Vol. 2, Issue 11, ISSN 2250-2459 pp. 703-713 2012*.

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