AGC CONTROLLERS TO OPTIMIZE LFC REGULATION IN DEREGULATED POWER SYSTEM

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ABSTRACT

This paper presents the AGC controllers to regulate the system frequency and to regulate the power generation of various GENCOs at scheduled levels in a deregulated power system by optimizing the parameters of controller using Evolutionary Real coded genetic algorithm (RCGA). The performance of the controller is investigated on a two-area interconnected power system consisting of Hydro-Thermal unit in one area and Thermal-Gas unit in the second area. The main goal of the optimization method is to improve the dynamics of LFC such as improving of the transient response of frequency and tie-line power oscillations and to optimizing the Power generated by various GENCOs according to the bilateral contracts scheduled between GENCOs and DISCOs in an interconnected multi-area deregulated power system. In the present paper the optimal feedback controller and a proportional-integral-derivative controller were used. The simulation results show the PID controller tuned by the proposed algorithm exhibits improved dynamic performance over optimally tuned Feedback controller.

KEYWORDS: *AGC controllers, Bilateral Contracts, Deregulated Power System, Real Coded Genetic algorithm (RCGA).*

I. INTRODUCTION

In deregulated scenario, automatic generation control is one of the most important ancillary services to be maintained for minimizing frequency deviations, imbalance of generation and load demand, and for regulating tie-line power exchange, facilitating bilateral contracts spanning over several control areas and to maintain a reliable operation of the interconnected transmission system. The requirement for improving the efficiency of power production and delivery and with intense participation of independent power producers motivates restructuring of the power sector. In deregulated scenario, new organizations, market operators, such as independent system operators (ISOs), are responsible for maintaining the real-time balance of generation and load for minimizing frequency deviations and regulating tie-line flows, and facilitates bilateral contracts spanning over various control areas. The demand being constantly fluctuating and increasing, and hence there is a need to expand the generation by introducing new potential generating plants such as gas fired power plants which are usually operated as peak power plants into the power market. With the trends developing in the combined cycle gas turbine based power plants having high efficiency and generation capacities more than 100 MW makes them suitable for providing peak loads and also can be operated as base load power plants.

The paper is organized as follows: Section II presents the detailed concepts of deregulated power system and its model in SIMULINK platform. In section III, the controllers used for maintaining the LFC regulation is discussed. Section IV presents an overview of the Real Coded Genetic Algorithm and its implementation aspects. The section V emphasizes on the simulation of the controllers with the proposed algorithm in a two area deregulated power system. Finally the conclusions were presented in section VI.

II. MULTI-AREA DEREGULATED POWER SYSTEM

The electrical industry over the years has been dominated by an overall authority known as vertical integrated utility (VIU) having authority over generation, transmission and distribution of power within its domain of operation [1]-[3], [11]. With the emerging or various independent power producers (IPPs) in the power market motivates the necessity of deregulation of the power system were the power can be sold at a competitive price performing all functions involved in generation, transmission, distribution and retail sales. With restructuring the ancillary services is no longer an integral part of the electricity supply, as they used to be in the vertically integrated power industry structure. In a deregulated environment, the provision of these services must be carefully managed so that the power system requirements and market objectives are adequately met. The first step in deregulation is to unbundle the generation of power from the transmission and distribution however, the common LFC goals, i.e. restoring the frequency and the net interchanges to their desired values for each control area remains same. Thus in a deregulated scenario generation, transmission and distribution is treated as separate entities [1], [6]-[11]. As there are several GENCOs and DISCOs in the deregulated structure, agreements/ contracts should be established between the DISCOs and GENCOs with in the area or with interconnected GENCOs and DISCOs to supply the regulation. The DISCOs have the liberty to contract with any available GENCOs in its own or other areas. Thus, there can be various combinations of the possible contracted scenarios between DISCOs and GENCOs. A DISCO having contracts with GENCOs in another control area are known as "Bilateral transactions" and within same area is known as "POOL transactions".

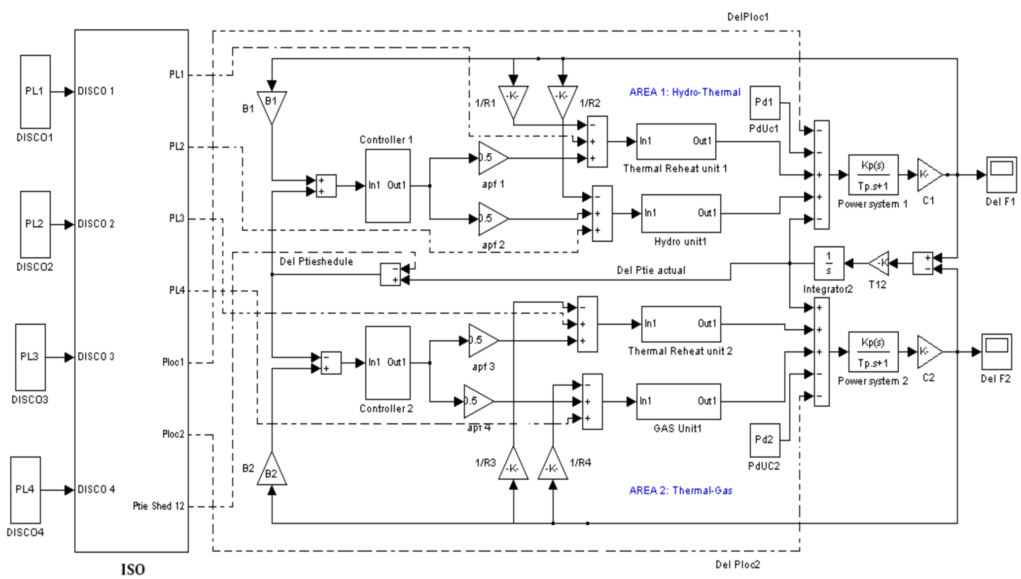


Figure: 1. Block diagram representation of two area Deregulated power system

The concept of DISCO Participation Matrix (DPM) [1], [2], [11] is introduced to express these possible contracts in the generalized model. DPM is a matrix with the number of rows equal to the number of GENCOs and the number of columns equal to the number of DISCOs in the overall system. The entities of DPM are represented by the contract participation factor *(cpf_{ij})* which corresponds to the fraction of total load contracted by any $DISCO_j$ towards any $GENCO_i$:

$$DPM = \begin{bmatrix} cpf_{11} & cpf_{12} & cpf_{1j} & . & . & cpf_{1n} \\ cpf_{21} & cpf_{22} & cpf_{2j} & . & . & cpf_{2n} \\ cpf_{i1} & cpf_{i2} & cpf_{ij} & . & . & cpf_{in} \\ . & . & . & . & . & . \\ cpf_{n1} & cpf_{n2} & cpf_{n3} & . & . & cpf_{nn} \end{bmatrix} \quad (1)$$

The sum of all entries in each column of DPM is unity.

$$\sum_i cpf_{ij} = 1 \quad (2)$$

Under steady state the power equations in deregulated environment are,

$$\Delta P_{d\,i} = \Delta P_{LOC\,i} + \Delta P_{UC\,i} \quad (3)$$

$$\text{Where } \Delta P_{LOC\,i} = \sum \Delta P_{LC\,i} \quad (4)$$

The scheduled contracted power exchange is given by:

$\Delta P_{tie12}^{scheduled}$= (Demand of DISCOs in area2 from GENCOs In area1) - (Demand of DISCOs in area1 from GENCOs in area2) (5)

The actual power exchanged in Tie-line is given by:

$$\Delta P_{tie12}^{actual} = \frac{2\pi T12}{S}(\Delta f_1 - \Delta f_2) \quad (6)$$

At any time the tie-line power error is given by:

$$\Delta P_{tie12}^{Error} = \Delta P_{tie12}^{actual} - \Delta P_{tie12}^{scheduled} \quad (7)$$

ΔP_{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:

$$ACE_1 = B_1 \Delta f_1 + \Delta P_{tie12}^{Error} \quad (8)$$

$$ACE_2 = B_2 \Delta f_2 + a_{12} * \Delta P_{tie12}^{Error} \quad (9)$$

$$\text{Where } a_{12} = -P_{r1}/P_{r2}$$

The total power supplied by i^{th} GENCO is given by:

$$\Delta P_{gki} = \Delta P_{mki} + apf_{ki} \sum \Delta P_{UC\,i} \quad (10)$$

$$\text{Where } \Delta P_{mki} = \sum_{j=i}^{N} cpf_{ij}\, \Delta P_{Lcj} \quad (11)$$

ΔP_{gki} is the desired total power generation of a $GENCO_i$ in area k and must track the contracted and un-contracted demands of the DISCOs in contract with it in the steady state.

III. AGC CONTROLLERS

Several control strategy such as integral control, optimal control, variable structure control have been used to control the frequency and to maintain the scheduled regulation between the interconnected areas. One major advantage of integral controller is that it reduces the steady state error to zero, but do not perform well under varying operating conditions and exhibits poor dynamic performance [6]-[8]. The controller based on optimal control and variable structure control needs feedback of most of state variables of the system which is practically difficult to have access and measure them in a large interconnected system. In this paper is focused on optimization of feedback controller and Proportional-Integral-Derivative (PID) controller.

3.1. Optimal Feedback Controller

An optimal AGC strategy based on the linear state regulatory theory requires the feedback of all state variables of the system for its implementation, and an optimal control feedback law is obtained by solving the non-linear Riccati equation using suitable computational technique. In practical environment access to all variables is limited and also measuring all of them is impossible [3]. To solve the problem some of the measurable variables are selected for the feedback control law. The two area power system, shown in Fig.1 can be described by the following controllable and observable time-invariant state space representation as:

$$\dot{X} = A.X + B.U \quad (12)$$

$$Y = C.X \quad (13)$$

Where X is the state vector and U is the vector of contracted and un-contracted power demands of the DISCOs.

$$X = [\,\Delta f_1 \;\; \Delta f_2 \;\; \Delta P_{g1} \;\; \Delta P_{g2} \;\; \Delta P_{g3} \;\; \Delta P_{g4} \;\; \int ACE_1 \;\; \int ACE_2 \;\; \Delta P_{tie12,act}]^T \quad (14)$$

and

$$U = [\,\Delta P_{L1} \;\; \Delta P_{L2} \;\; \Delta P_{L3} \;\; \Delta P_{L4} \;\; \Delta P_{d1} \;\; \Delta P_{d2}]^T \quad (15)$$

for the system defined by the Eq.(12) and (13), the feedback control law is given as,

$$U = -K.Y \quad (16)$$

Where K is the feedback gain matrix. In this paper using ITAE as a performance criterion to be optimize the feedback gains of the controller is tuned using Evolutionary Real coded Genetic algorithms.

3.2. PID Controller

The most popular approach adopted for AGC in an inter-connected power system is the use of Proportional-Integral-Derivative (PID) controller [7]. In LFC problem the frequency deviations and the deviations in the tie-line are weighted together as a linear combination to a single variable called the Area control error (ACE), and is used as a control signal that applies to governor set point in each area. By taking ACE as the system output, the control vector for a PID controller is given by:

$$U_i = -\left[K_{pi} ACE_i + K_{Ii} \int ACE_i \, dt + K_{di} \frac{d(ACE_i)}{dt}\right] \quad (17)$$

Where K_p, K_d, K_I are the proportional, derivative and integral gains of PID controller. It is well known that the conventional method to tune gains of PID controller with numerical analyses is tedious and time consuming. In this strategy, using ITAE as a performance criterion to be optimize the PID gains are tuned using Real coded Genetic algorithms to improve the dynamics of LFC in a deregulated power system.

IV. EVOLUTIONARY ALGORITHMS

In traditional approach sequential optimization, several iterations are required to determine the optimal parameters for an objective function to be optimized. When the number of parameters to be optimize is large the classical techniques requires large number of iterations and computation time [5]. The evolutionary algorithms such as Genetic algorithms emerges as an alternative for optimizing the controller gains of a multiarea AGC system more effectively than the traditional methods [9],[17].

4.1. Real Coded Genetic algorithm

Genetic algorithm (GA) is an optimization method based on the mechanics of natural selection. In nature, weak and unfit species within their environment are faced with extinction by natural selection. The strong ones have greater opportunity to pass their genes to future generations. In the long run, species carrying the correct combination in their genes become dominant in their population. Sometimes, during the slow process of evolution, random changes may occur in genes. If these changes provide additional advantages in the challenge for survival, new species evolve from the old ones. Unsuccessful changes are eliminated by natural selection. In real-coded genetic algorithm (RCGA), a solution is directly represented as a vector of real parameter decision variables, representation of the solutions very close to the natural formulation of the problem [4], [9],[17]. The use of floating-point numbers in the GA representation has a number of advantages over binary encoding. The efficiency of the GA gets increased as there is no need to encode/decode the solution variables into the binary type.

4.1.1 Chromosome structure

In GA terminology, a solution vector known as an individual or a chromosome. Chromosomes are made of discrete units called genes. Each gene controls one or more features of the chromosome [9],

[17]. The chromosome consisting of gains (K) of feedback controller and gains (K_p, K_d & K_I) of a PID controller is modeled as its genes.

4.1.2 Fitness-Objective function evaluation

The objective here is to minimize the deviation in the frequency and the deviation in the tie line power flows and these variations are weighted together as a single variable called the ACE. The fitness function is taken as the Integral of time multiplied absolute value (ITAE) of ACE [1], [2]. An optional penalty term is added to take care of the transient response specifications viz. settling time, over shoots, etc. Integral of time multiplied absolute value of the Error (ITAE), is given by:

$$ITAE = \int_0^{Tsim} t\left|e(t)\right| dt \quad (18)$$

Where $e(t)$= error considered.

The fitness function to be minimized is given by:

$$J = \int_0^{Tsim} \left(\beta_1 \left|\Delta f_1\right| + \beta_2 \left|\Delta f_2\right| + \left|\Delta P_{Tie12}^{Error}\right|\right) dt + FD \quad (19)$$

$$\text{Where FD} = \alpha_1 \text{ OS} + \alpha_2 \text{ TS} \quad (20)$$

Where Overshoot (OS) and settling time (TS) for 2% band of frequency deviation in both areas is considered for evaluation of the FD [10].

4.1.3 Selection

Selection is a method of selecting an individual which will survive and move on to the next generation based on the fitness function from a population of individuals in a genetic algorithm. In this paper tournament selection is adopted for selection [8], [9], [17]. The basic idea of tournament selection scheme is to select a group of individuals randomly from the population. The individuals in this group are then compared with each other, with the fittest among the group becoming the selected individual.

4.1.4 Crossover

The crossover operation is also called recombination. This operator manipulates a pair of individuals (called parents) to produce two new individuals (called offspring or children) by exchanging corresponding segments from the parents' coding [9], [11], [17]. In this paper simple arithmetic crossover is adopted.

4.1.5 Mutation

By modifying one or more of the gene values of an existing individual, mutation creates new individuals and thus increases the variability of the population [9],[17]. In the proposed work Uniform mutation is adopted.

4.1.6 Elitism

Elitism is a technique to preserve and use previously found best solutions in subsequent generations of EA [9], [17]. In an elitist EA, the population's best solutions cannot degrade with generation.

4.2. Pseudo code for the proposed RCGA

Step 1: Initialization

Set gen=1. Randomly generate N solutions to form the first population, $P_{initial}$. Evaluate the fitness of solutions in $P_{initial}$. Initialize the probabilities of crossover *(pc)* and mutation (*pm*).

While (gen ≤ Max number of generations)

Step 2: Selection

Select the individuals, called *parents* that contribute to the population at the next generation. In the proposed GA tournament selection is used.

Step 3: Crossover

Generate an offspring population Child,

if pc >rand,

3.1. Choose one best solutions x from $P_{initial}$ based on the fitness values and random solution y from the population for crossover operation.

3.2. Using a crossover operator, generate offspring and add them back into the population.

$$Child_1 = r\ parent_1 + (1 - r)\ parent_2;$$

$$Child_2 = r\ parent_2 + (1 - r)\ parent_1;$$

end if

Step 4: Mutation

Mutation alters an individual, parent, to produce a single new individual, child.

if pm >rand,

Mutate the selected solution with a predefined mutation rate.

end if

Step 5: Fitness assignment

The fitness function defined by Eqs. (19) is minimized for the feasible solution

Step 6: Elitism

The selected number of Elite solutions (best solutions) is preserved in subsequent generations in the population.

Step 7: stopping criterion

If the maximum number of generations has reached then terminate the search and return to the current population, else, set gen=gen+1and go to Step 2.

end while

The values of GA operator used for optimization is presented in appendix B.

V. SIMULATION

To investigate the performance of the proposed RCGA, a two area power system consisting of hydro-thermal system in one area and thermal-gas plant system in second area is considered. In each area two GENCOs and two DISCOs are considered with each GENCO demanding a load demand of 0.1puMW contracted towards the GENCOs according to the Bilateral contracts established between various GENCOs and DISCOs. The concept of a "*DISCO participation matrix*" (DPM) is used for the simulation of contracts between GENCOs and DISCOs. In a Restructured AGC system, a DISCO asks/demands a particular GENCO or GENCOs within the area or from the interconnected area for load power. Thus, 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 factors* and the pu MW load of a DISCO. These signals will carry information as to which GENCO has to follow a load demanded by which DISCO. Using Integral of Time multiplied by Absolute Error the gains of the feedback controller and Proportional-Integral and Derivative controller is tuned by using Evolutionary Real coded Genetic algorithm. The simulation is done in MATLAB/SIMULINK platform and the power system parameters used for simulation were presented in appendix A.
The GENCOs in each area participates in ACE defined by the following *apfs:*

$apf_1 = 0.5;$ $apf_3 = 0.5;$

$apf_2 = 1 - apf_1 = 0.5;$ $apf_4 = 1 - apf_3 = 0.5;$

5.1. Scenario I: Bilateral transactions

In this scenario, DISCOs have the freedom to have a contract with any GENCO in their or another areas. Consider that all the DISCOs contract with the available GENCOs for power as per following

DPM. All GENCOs participate in the LFC task. It is assumed that a large step load 0.1 pu is demanded by each DISCOs in areas 1 and 2.

```
DPM=[ 0.4 0.25 0.0 0.3
      0.3 0.25 0.0 0.0
      0.1 0.25 0.5 0.7
      0.2 0.25 0.5 0.0];
```

The frequency deviations of two areas, GENCOs power generation, Tie-line power flow and Area control error for the given operating conditions is depicted in Fig.2 to Fig.6:

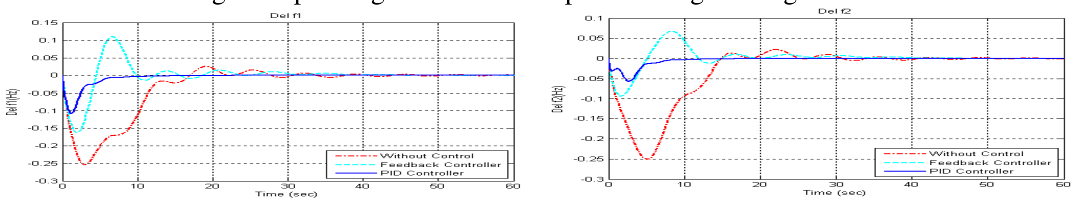
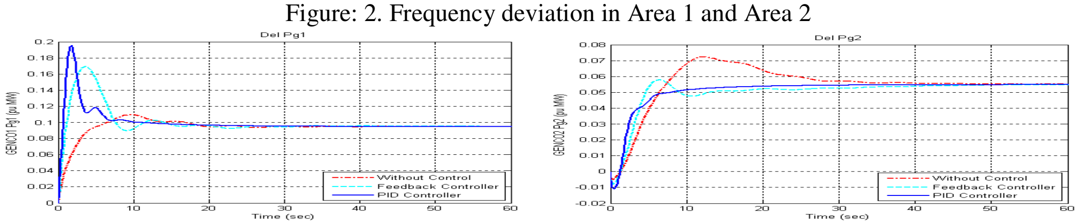
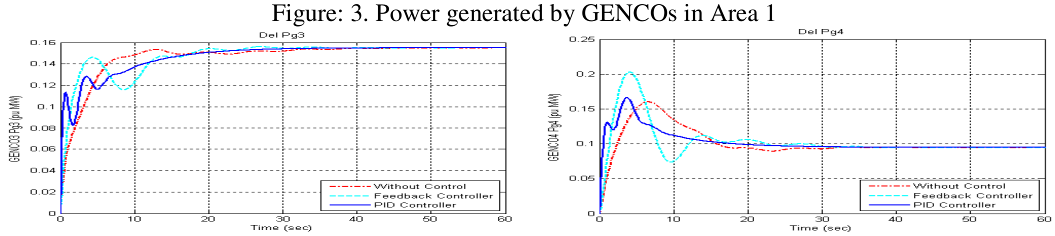


Figure: 2. Frequency deviation in Area 1 and Area 2



a. GENCO 1: Thermal power plant b. GENCO 2: Hydro power plant

Figure: 3. Power generated by GENCOs in Area 1



a. GENCO 3: Thermal power plant b. GENCO 4: Gas power plant

Figure: 4. Power generated by GENCOs in Area 2

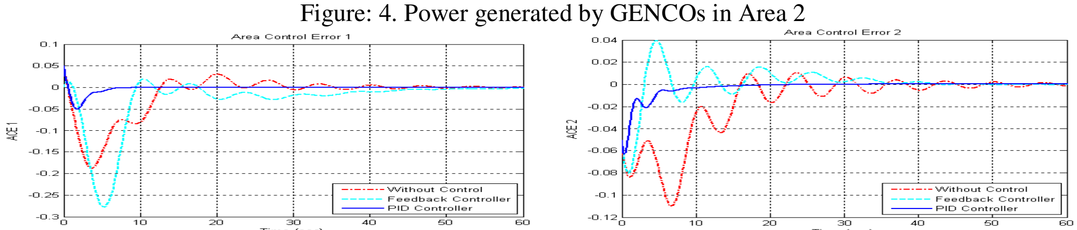


Figure: 5. Area Control Error (ACE) in Area 1 and Area 2

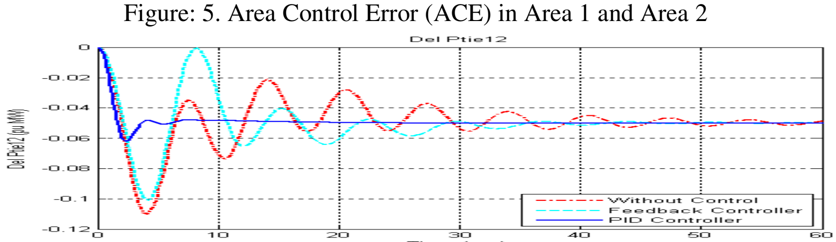


Figure: 6. Tie-line power Del Ptie-line$_{12}$- $_{\text{Scheduled}}$

From the simulation results shown in fig:6 due to the bilateral contracts existing between GENCOs and DISCOs of area 1 and area 2, the tie-line power converges to a steady state value of $\Delta P_{tie12\text{-}schedule}$=-0.05 puMW. At steady state the total generation should match the total demand contracted by the DISCOs, Thus the generation in area 1 and area 2 converges to the scheduled values as governed by ISO and is tabulated in table 1:

Table: 1. Power generated by GENCOs

GENCOs Generation	Scheduled	Uncontrolled	Feedback controller	PID controller
del Pg_1	0.095	0.0949	0.0949	**0.095**
del Pg_2	0.055	0.055	0.0548	**0.055**
del Pg_3	0.155	0.154	0.1549	**0.155**
del Pg_4	0.095	0.095	0.0949	**0.095**
del $Ptie_{12}$	-0.050	-0.048	-0.050	**-0.050**

The time domain specifications such as Overshoot and settling time for frequency and tie-line dynamics for the given operating conditions is tabulated in table 2.

Table: 2. Time domain specifications

	Uncontrolled		Feedback controller		PID controller	
	Max Overshoot	**Settling Time (sec)**	**Max Overshoot**	**Settling Time(sec)**	**Max Overshoot**	**Settling Time(sec)**
del f1	-0.253	20.963	-0.162	**10.103**	**-0.108**	10.671
del f2	-0.250	23.855	-0.093	11.752	**-0.057**	**9.865**
del P_{tie12}	-0.108	22.168	-0.100	10.927	**-0.061**	**4.026**

5.2. Scenario II: Contract violation by DISCOs in area 1

It may happen that a DISCO violates a contract by demanding more power than that specified in the contract. This un-contracted power must be supplied by the GENCOs in the same area as the DISCO. Consider scenario I with a modification that DISCOs in area 1 demands additional 0.05 pu MW of un-contracted power in excess. Let $\Delta P_{L,uc1}$=0.05pu. This excess power should be supplied by GENCOs in area 1 and the generation in area 2 remains unchanged. The frequency and Tie-line deviations, power generated by GENCOs and Area control error were depicted in Fig: 7 to Fig. 11:

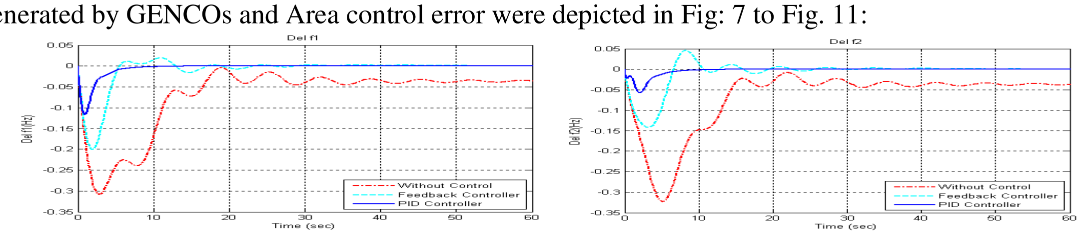
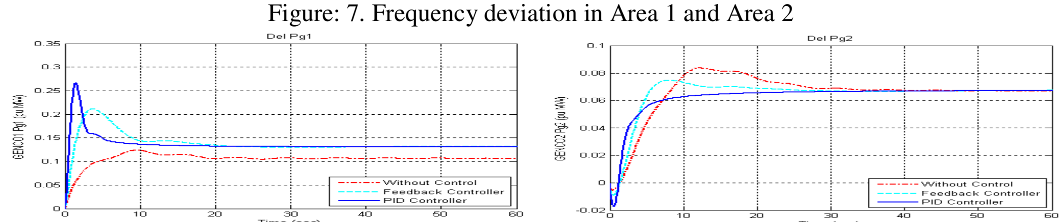
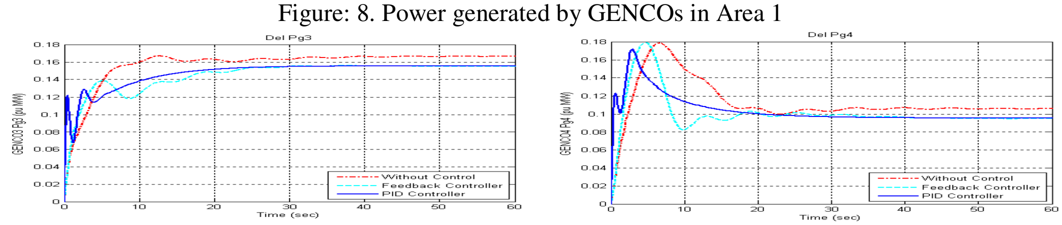


Figure: 7. Frequency deviation in Area 1 and Area 2



a. GENCO 1: Thermal power plant b. GENCO 2: Hydro power plant

Figure: 8. Power generated by GENCOs in Area 1



a. GENCO 3: Thermal power plant b. GENCO 4: Gas power plant

Figure: 9. Power generated by GENCOs in Area 2

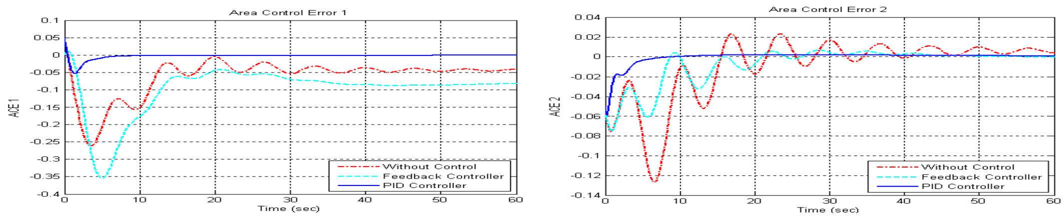


Figure: 10. Area Control Error (ACE) in Area 1 and Area 2

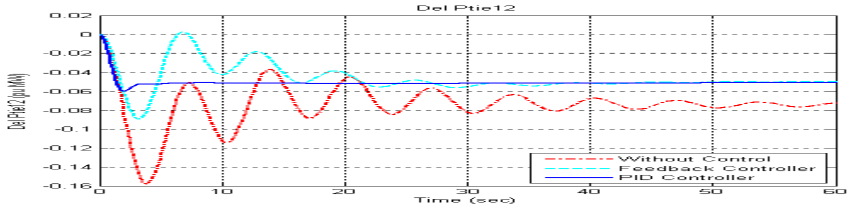


Figure: 11. Tie-line power Del Ptie-line$_{12}$- Scheduled

From the simulation results shown in fig:8-9 in the event of contract violation by the DISCOs in area 1, it is observed that the excess power demand is contributed by the GENCOs in the same area, while the generation in area 2 and the scheduled tie-line power remains unchanged. At steady state the total generation should match the total demand contracted by the DISCOs, Thus the generation in area 1 and 2 converges to the scheduled values as governed by ISO and is tabulated in table 3.

Table: 3. Power generated by GENCOs

GENCOs Generation	Scheduled	Uncontrolled	Feedback controller	PID controller
del Pg_1	0.095	0.1070	0.1328	**0.1320**
del Pg_2	0.055	0.0668	0.0674	**0.0672**
del Pg_3	0.155	0.1667	0.1549	0.1550
del Pg_4	0.095	0.1061	0.0947	0.0950
del $Ptie_{12}$	-0.050	-0.0723	-0.0498	-0.0500

The time domain specifications such as Overshoot and settling time for frequency and tie-line dynamics for the given operating conditions is tabulated in table 4.

Table: 4. Time domain specifications

	Uncontrolled		Feedback controller		PID controller	
	Max Overshoot	**Settling Time (sec)**	**Max Overshoot**	**Settling Time(sec)**	**Max Overshoot**	**Settling Time(sec)**
del f1	-0.3078	26.747	-0.199	**5.928**	**-0.116**	8.961
del f2	-0.322	24.096	-0.141	10.598	**-0.056**	**8.766**
del P_{tie12}	-0.157	22.409	-0.0889	15.089	**-0.059**	**3.701**

5.3. Scenario III: Contract violation by DISCOs in area 2

Consider scenario I with a modification that DISCOs in area 2 demands additional 0.05 pu MW of un-contracted power in excess. Let $\Delta P_{L,uc2}$=0.05pu. The frequency and Tie-line deviations, power generated by GENCOs and Area control error were depicted in Fig: 12 to Fig. 16:

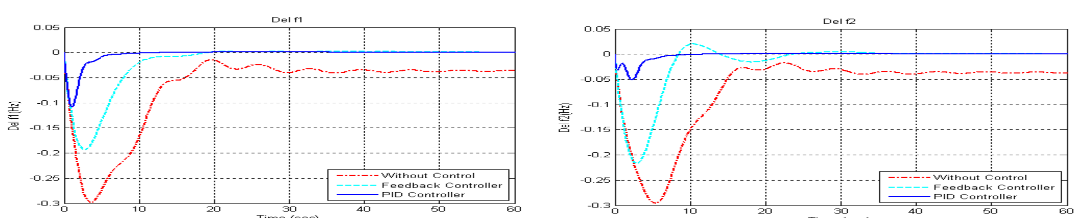
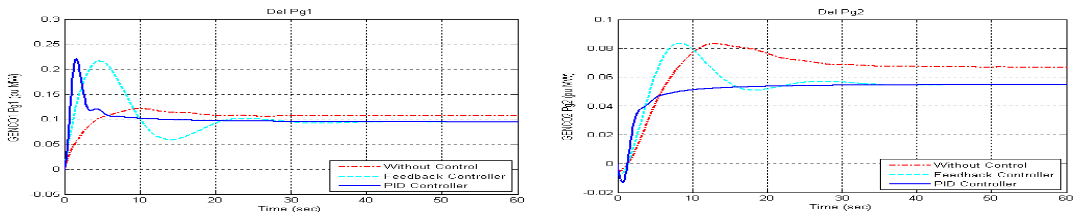
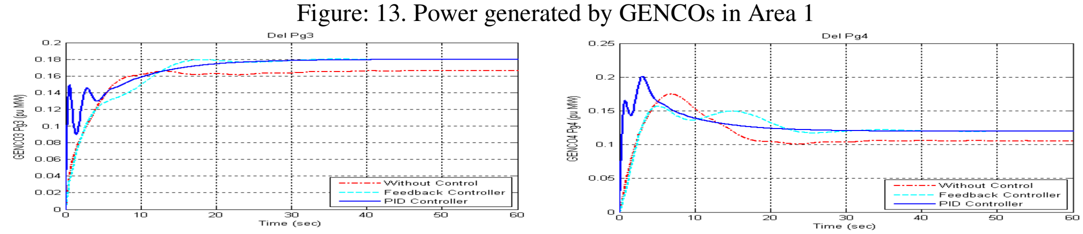


Figure: 12. Frequency deviation in Area 1 and Area 2



a. GENCO1: Thermal power plant b. GENCO 2: Hydro power plant

Figure: 13. Power generated by GENCOs in Area 1



a. GENCO 3: Thermal power plant b. GENCO 4: Gas power plant

Figure: 14. Power generated by GENCOs in Area 2

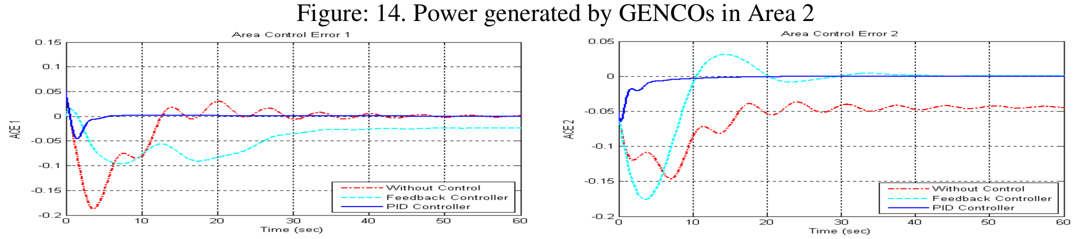


Figure: 15. Area Control Error (ACE) in Area 1 and Area 2

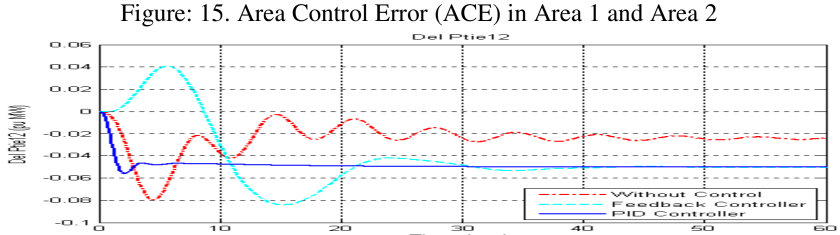


Figure: 16 Tie-line power Del Ptie-line$_{12}$-$_{\text{Scheduled}}$

From the simulation results shown in fig:13-14 in the event of contract violation by the DISCOs in area 2, it is observed that the excess power demand is contributed by the GENCOs in the same area, while the generation in area 1 and the scheduled tie-line power remains unchanged. At steady state the total generation should match the total demand contracted by the DISCOs, Thus the generation in area 1 and 2 converges to the scheduled values as governed by ISO and is tabulated in table 5.

Table: 5. Power generated by GENCOs

GENCOs Generation	**Scheduled**	**Uncontrolled**	**Feedback controller**	**PID controller**
del Pg$_1$	0.095	0.1071	0.095	0.095
del Pg$_2$	0.055	0.0668	0.0548	0.055
del Pg$_3$	0.155	0.1667	0.180	**0.180**
del Pg$_4$	0.095	0.1059	0.120	**0.120**
del Ptie$_{12}$	-0.050	-0.0237	-0.0498	-0.050

The time domain specifications such as Overshoot and settling time for frequency and tie-line dynamics for the given operating conditions is tabulated in table 6.

Table: 6. Time domain specifications

	Uncontrolled		**Feedback controller**		**PID controller**	
	Max Overshoot	**Settling Time (sec)**	**Max Overshoot**	**Settling Time(sec)**	**Max Overshoot**	**Settling Time(sec)**
del f1	-0.298	21.448	-0.193	11.744	**-0.108**	**8.092**
del f2	-0.295	24.096	-0.216	9.446	**-0.051**	**8.684**

del P_{tie12}	-0.079	16.385	-0.0837	19.914	**-0.055**	**3.947**

The convergence characteristic of the objective function given in Eqs. (19) with the algorithm is shown in Fig. 17.

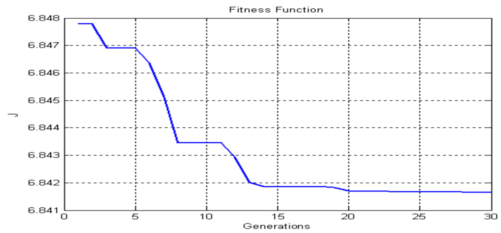


Figure.17. Convergence characteristic of the objective function

VI. CONCLUSIONS

From simulation results the dynamic response obtained for various operating conditions, it is inferred that the implementation of PID controller optimized by Evolutionary Real Coded Genetic Algorithm results in an appreciable reduction in the magnitude of overshoot, converging to steady state without steady state error, and within convincible settling time for Δf_1, Δf_2, and ΔP_{tie12}. Also the PID controller tuned by the algorithm has successfully traced the generation of individual GENCOs in accordance to the schedule laid by the ISO and also ensures zero area control error at steady state in both areas over a wide range of operating conditions. From the convergence characteristics it is inferred that the proposed algorithm converges rapidly to the optimal solution with in less number of iterations. The overall performance of PID controller tuned by the proposed algorithm exhibits improved dynamic performance over optimally tuned feedback controller for different operating conditions considered.

REFERENCES

[1] Elyas Rakhshani , Javad Sadeh, (2010) - Practical viewpoints on load frequency control problem in a deregulated power system- *Energy Conversion and Management* 51,pp 1148–1156,
[2] Y.L.Karnavas,K.S.Dedousis, (2010)-Overall performance evaluation of evolutionary designed conventional AGC controllers for interconnected electric power system studies in a deregulated market environment- *International journal of Engineering, Science and Technology*,Vol. 2.
[3] Prabhat Kumar, Safia A Kazmi, Nazish Yasmeen,(2010) -Comparative study of automatic generation control in traditional and deregulated power environment- *World Journal of Modelling and Simulation Vol. 6 No. 3*
[4] Pingkang Li Xiuxix Du ,(2009) - Multi-Area AGC System Performance Improvement Using GA Based Fuzzy Logic Control- *The International Conference on Electrical Engineering,*
[5] Janardan Nanda,S.Mishra, Lalit Chandra Saikia, (2009)- Maiden application of Bacterial Foraging based optimization technique in multiarea Automatic generation control,-*IEEE Transactions on power systems, Vol. 24. No.2,pp 602-609,*
[6] Hassan Bevrani and Takashi Hiyama-Multiobjective PI/PID Control Design Using an Iterative Linear Matrix Inequalities Algorithm-*International Journal of Control, Automation, and Systems, vol. 5, no. 2, pp. 117-127, April 2007.*
[7] Hossein Shayeghi, Heidar Ali Shayanfar, Aref Jalili- Multi Stage Fuzzy PID load frequency controller in a Restructured power system - *Journal of Electrical Engineering, VOL. 58, NO. 2, 2007, 61–70.*
[8] Reza Hemmati, Sayed Mojtaba Shirvani Boroujeni, Hamideh Delafkar and Amin Safarnezhad Boroujeni (2011)- PID Controller Adjustment using PSO for Multi Area Load Frequency Control-*Australian Journal of Basic and Applied Sciences, 5(3): 295-302, 2011.*
[9] A. Konak et al, (2006) - Multi-objective optimization using genetic algorithms: A tutorial- */ Reliability Engineering and System Safety*.
[10] Bevrani, Hassan and Mitani, Yasunori and Tsuji, Kiichiro, (2003) Robust LoadFrequency Regulation In a New Distributed Generation Environment. *In Proceedings IEEE Power Engineering Society General Meeting.*
[11] V. Donde, M. Pai, I. Hiskens,(2001). Simulation and Optimization in an AGC System after Deregulation. *IEEE Transactions on Power Systems, 16(3): 481–488,*
[12] Aimin Zhou, Bo-Yang Qu, Hui Li, Shi-Zheng Zhao, Ponnuthurai Nagaratnam Suganthan, Qingfu Zhang- *Multiobjective evolutionary algorithms: A survey of the state of the art*

[13] V. Donde.M. A. Pai,I. A. Hiskens-Simulation of Bilateral Contracts in an AGC System After Restructuring,
[14] K.S.S. Ramakrishna, T.S. Bhatti, (ICEE 2006),- Load frequency control of interconnected hydro-thermal power systems-*International Conference on Energy and Environment 2006*
[15] Preghnesh Bhatt, S.P. Ghoshal, and Ranjit Roy(*2010*)- Automatic Generation Control of Two-area Interconnected Hydro-Hydro Restructured Power System with TCPS and SMES- *Proc. of Int. Conf. on Control, Communication and Power Engineering 2010.*
[16] Preghnesh Bhatt, S.P. Ghoshal, and Ranjit Roy(*2010*)- Optimized multi area AGC simulation in restructured power systems- International *Journal of Electrical Power & Energy Systems*, *Volume 32, Issue 4, May 2010, Pages 311-322.*
[17] D.Goldberg,(1989)- *Genetic algorithm in search optimization and machine learning*: Addison-Wesley.
[18] P. Kundur- *Power system stability and control*: Mc Graw Hill.

APPENDIX A: Parameters values of Power System

Area 1

GENCO 1: Tg_{11}=0.0875; Tt_{11}=0.4; Kr_{11}=.33; Tr_{11}=10; R_1=3;

GENCO 2: Tg_{12}=0.1; T_{21}=0.513; T_{31}=10; Tw_1=1; R_2=3.125;

B_1=0.532

Area 2

GENCO 3: Tg_{21}=0.075; Tt_{21}=0.375; Kr_2=.33; Tr_2=10; R_3=3.125;

GENCO 4: Tggas=1.5; T_{tgas}=0.1; T_{lgas}=5; R_4=3.375;

B_2=0.495;

T_{12}=0.543.

APPENDIX B: Genetic Algorithm parameters

No of population	: 100
Maximum no of generations	: 30
Crossover	: Arithmetic
Crossover probability (*pc*)	: 0.95
Mutation	: Uniform
Mutation probability (*pm*)	: 0.1
Elitism	: Yes
No. of Elite solutions	: 2

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