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AGC Tuning of an Interconnected System after Deregulation Using Genetic Algorithms

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Abstract: - Currently, the electric power industry is in transition from vertically integrated utilities to an industry that will incorporate competitive companies. This increases the complexity of the load frequency issue and calls for more insight and research. In this context, the tuning of a two-area AGC system after deregulation is not yet discussed and is studied in this work. The effect of bilateral contracts on the dynamics of the system is taken into account and the concept of DISCO participation matrix for these bilateral contracts is simulated. Genetic algorithms are adopted in order to obtain the optimal parameters of the load-frequency controllers as well as of the frequency biases. The performances of the tuned two–area AGC system are obtained using an appropriate Matlab/Simulink model and are found comparable and better to those of the same AGC system found in literature.

Key-Words: Automatic generation control, deregulation, bilateral contracts, power system control, tuning by GA.

1. Introduction

It is obvious nowadays that in a restructured electric power system environment, the engineering aspects of planning and operation have to be reformulated. The open market system will consist of generation companies (GenCo's), distribution companies (DisCo's) and transmission companies (TransCo's) as well as an independent system operator (ISO). In most of the recent reported strategies, attempts have been made to adapt well-tested classical AGC schemes to the changing environment of power system operation under deregulation [1-2]. A comprehensive study on simulation and optimization in an AGC system after deregulation has been carried out by Donde and Pai [3]. In the same work the concept of DisCo participation matrix (DPM) is proposed that helps the visualization and implementation of the contracts. The critical parameters in order to tne such a system are found to be the feedback integral gains of the integral controllers as well as the frequency biases of the two areas. In this work, all the three components of a proportional plus integral plus derivative (PID) load frequency controllers are being examined, and the two-area AGC system (2aAGCs) block diagram in restructured environment of [3] is used to demonstrate the tuning procedure. Modifications are made in the area controllers which are extended to be PI and PID ones as well. The paper is organized as follows. In the next section the block diagram of the 2aAGCs is described and its aspects are discussed. GAs details and the tuning procedure are given next. The GA tuning is applied to three case studies and the simulation results are summarized in fourth section and commented in the conclusion section.

2. The New Environment for AGC

The traditional AGC is well discussed in [4-5], while research work in deregulated AGC is contained in [1-3],[6-8]. In the new restructured environment (Fig. 1), GenCos sell power to various DisCos at competitive prices. DisCos have the liberty to choose the GenCos for their contracts. They may or may not have contracts with the GenCos in their own area. This makes various combinations of GenCo-DisCo contracts possible in practice (Fig. 2).

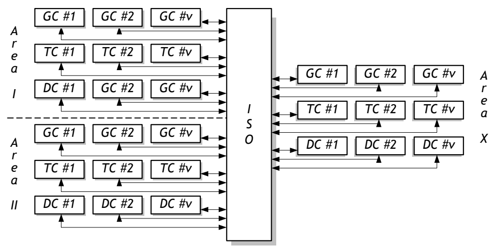

Fig. 1. *Interconnection between generation (GC), transmission (TC) and distribution (DC) companies in a deregulated environment.*

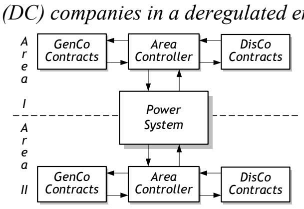

Fig. 2. *Schematic of a 2-area AGC model in restructured environment.*

In Fig. 3, the 2aAGCs block diagram shows how the bilateral contracts are incorporated in the traditional AGC system. The system is modeled in Matlab/Simulink and the area controllers are replaced with PID ones. Each area includes two identical GenCos and two DisCos. The controller's demand signal is distributed according to the "*apf*" (area participation factors) block. Each GenCo is represented by a governor and a turbine.

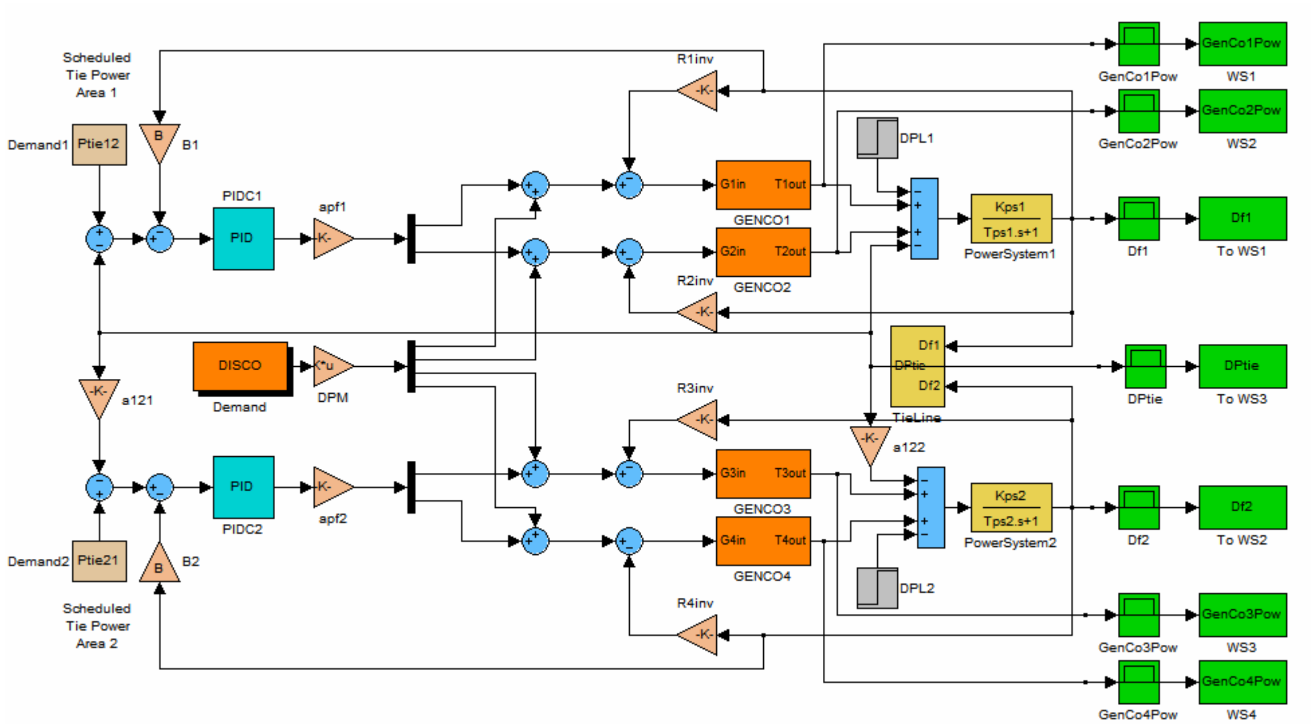

Fig. 3. *Two-area (double GenCo) AGC system with controllers in Matlab/Simulink.*

All the system data are given for clarity in the Appendix. In the DisCo block the four loads of the DisCos are stored. Depending on the contracts made between GenCos and DisCos, the DPM is set. 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 system (Eq. 1). Each entry in this matrix can be thought of as a fraction of a total load contracted by j^{th} DisCo towards the i^{th} GenCo and is called "contract participation factor" (Eq. 2).

$$\begin{array}{cc} & \begin{array}{cccc} DC1 & DC2 & DC3 & DC4 \\ \downarrow & \downarrow & \downarrow & \downarrow \end{array} \\ \mathbf{DPM}= & \begin{bmatrix} cpf_{11} & cpf_{12} & cpf_{13} & cpf_{14} \\ cpf_{21} & cpf_{22} & cpf_{23} & cpf_{24} \\ cpf_{31} & cpf_{32} & cpf_{33} & cpf_{34} \\ cpf_{41} & cpf_{42} & cpf_{43} & cpf_{44} \end{bmatrix} \begin{array}{l} \leftarrow GC1 \\ \leftarrow GC2 \\ \leftarrow GC3 \\ \leftarrow GC4 \end{array} \end{array} \tag{1}$$

where

$$cpf_{ij} = \frac{j^{th} \text{ DisCo's power demand out of } i^{th} \text{ GenCo [pu.MW]}}{j^{th} \text{ DisCo's total power demand [pu.MW]}} \tag{2}$$

Whenever a load demanded by a DisCo changes, it is reflected as a local load in the area to which this DisCo belongs. This corresponds to the local loads ΔP_{L1} and ΔP_{L2} 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 AGC. Coefficients that distribute ACE to several GenCos are termed as "ACE participation factors" (*apf*). Note that $\sum_{j=1}^{m} apf_j = 1$ where m is the number of GenCos. 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. These signals (which were absent from the traditional AGC scenario) describing the partial demands, are specified by the *cpf*s and the puMW load of a DisCo. These signals carry information as to *which GenCo* has to follow a load demanded by *which DisCo*. The scheduled steady state power flow on the tie-line is given as

$$\begin{aligned}\Delta P_{tie1-2}^{scheduled} &= (\text{Demand of DisCos in area II from GenCos in area I}) \\ &\quad - (\text{Demand of DisCos in area I from GenCos in area II})\end{aligned} \tag{3}$$

At any given time, the tie line power error is defined:

$$\Delta P_{tie1-2}^{error} = \Delta P_{tie1-2}^{actual} - \Delta P_{tie1-2}^{scheduled} \tag{4}$$

This 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,

$$\begin{aligned} ACE_1 &= B_1 \Delta f_1 + \Delta P_{tie1-2}^{error} \\ ACE_2 &= B_2 \Delta f_2 + \Delta P_{tie2-1}^{error} \end{aligned} \tag{5}$$

where $\Delta P_{tie2-1}^{error} = \left(-P_{r1}/P_{r2}\right) \Delta P_{tie1-2}^{error}$ and P_{r1}, P_{r2} are the rated powers of areas I and II, respectively. Consequently,

$ACE_2 = B_2 \Delta f_2 + a_{12} \Delta P_{tie1-2}^{error}$ where $a_{12} = -\mathrm{P}_{r1}/\mathrm{P}_{r2}$.

Therefore, in this work the required GenCos production is given by:

$$GENCO = DPM \cdot DISCO \tag{6}$$

Finally, for this work, the controllers gains as well as the frequency biases are set to be equal for both areas.

3. Genetic Algorithms Overview

Genetic algorithms (GA), a way to search randomly for the best answers to tough problems were first introduced by Holland [9]. Over the past years, it is becoming important to solve a wide range of search, optimization and machine learning problems. A GA is an iterative procedure which maintains a constant size population of candidate solutions. The algorithm begins with a randomly selected population of function inputs represented by string of bits. During each iteration step, called a generation, the structures in the current population are evaluated and on the basis of this evaluation, a new population of candidate solution is formed. That is. GA uses the current population of string to create a new population such that the strings in the new population are on average "better" than those in the current population. The idea is to use the best elements from the current population to help form the new population. If this is done correctly, then the new population will on average be "better" than the old population. Three basic processes – selection, mating (crossover) and mutation – are used to make the transition from one population generation to the next. The simplified genetic algorithm cycle based on the above is shown in Fig. 4.

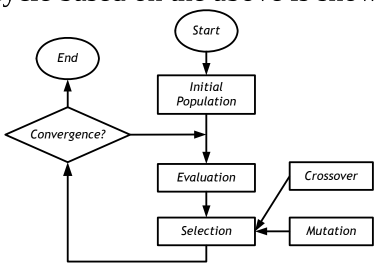

Fig. 4. *Simplified flowchart of a typical GA.*

3.1. GA's Processes

The above three steps are repeated to create each new generation. And it continues in this fashion until some stopping condition is reached (e.g. maximum number of generations or resulting new population not improving fast enough).

Selection: This is the first step of the three genetic operations. This determines which strings in the current population will be used to create the next generation. This is done by using a biased random selection methodology. That is, parents are randomly selected from the current population in such a way that the "best" strings in the population have the greatest chance of being selected. There are many ways to do this. One commonly used technique is roulette wheel parent selection [10] (used in the present work).

Crossover: It is a randomized yet structured recombination operation. Simple crossover may proceed in two steps. First, the newly reproduced strings in the mating pool are mated at random. Second, crossover of each pair of strings is done as follows:

(i) An integer position p along a string is selected at random in the intervals $[1,L-1]$, where L is the string length.

(ii) Two new strings are created by swapping all characters between position 1 and p inclusively.

Mutation: Reproduction and crossover effectively search and recombine the existing chromosomes. However, they do not create any new genetic material in the population. Mutation is capable of overcoming this shortcoming. It is an occasional random alteration of a string position. In the binary string representation, this simply means changing a 1 to 0 or vice versa. This random mutation provides background variation and occasionally introduces beneficial materials into the population.

3.2. GA's Parameters Selection

Genetic parameters - namely population size, crossover rate (P_c) and mutation rate (P_m)- are the entities that help to tune the performance of the GAs. The selection of values for these parameters plays an important role in obtaining an optimal solution. There are no deterministic rules to decide these values, but there are some general guidelines which can be followed to arrive at optimal values for these parameters and can which be found in [9].

Control Parameters Selected: First of all, the effect of population sizes for different test cases was observed. Different populations (20, 50, 60, 80, 100) were considered and it has been observed that the population size 50 or even 40 was satisfactory. After selecting the population size, the effect of mutation and crossover probabilities was examined. It has been found that suitable combination of mutation and crossover probabilities giving the best performances varies with test cases. Different combinations of mutation probabilities (0.0001, 0.001, 0.005, 0.01) and crossover probabilities (0.6, 0.8, 0.9, 1.0) were tested and it was found that P_c=1.0 and P_m=0.005 give the best performance for all the test cases.

Encoding: The design variables are mapped onto a fixed-length binary digit string which is constructed over the binary alphabet {0,1}, and is concatenated head-to-tail to form one long string called a chromosome. That is, every string contains all design variables. Each design variable is represented by a λ bit string. We have to determine the value of λ. It is shown by Lin and Hajela [11] that:

$$\lambda \geq \log_2 \frac{x^u - x^l}{\varepsilon} \tag{7}$$

where x^u=upper bound on x; x^l=lower bounds on x; ε=the resolution. For example, if ε=0.01, x^u=60.0, x^l=20.0, then $\lambda \geq 12$.

Decoding: The physical value of design variable x is computed from the following equation

$$x = x^l + I\frac{x^u - x^l}{2^\lambda - 1} \qquad (8)$$

For example, if ε=0.01, x^u=60.0, x^l=20.0 and λ=12, then the bit string 100000000001 is decoded to I=2049 and thus x=40.014652.

During the optimization process upper and lower bounds of all the gain settings were selected as [-10, 10] respectively, and the bit size (gene length) of each variable as 20 (i.e. λ=20).

3.3. Objective Function

The optimal values of K's and B depend on the cost function used for optimization. In literature, the integral of square error criterion is chosen and is used by the GA in this work for the Cases described below.

$$J = \int_0^T \left(\Delta f_1^2 + \Delta P_{tie}^2\right) dt \qquad (9)$$

4 Case Studies and Simulation Results

***Case 1**: Base Case [3]*: The GenCos in each area participate equally in AGC; i.e., all four *apf* values are equal to 0.5. Contracts are made only between DisCos in area I and GenCos in area I, to purchase 0.1 puMW for each of them. In other words the load change occurs only in area 1. The following data are applicable for this case:

$$DPM = \begin{bmatrix} 0.5 & 0.5 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}, DISCO = \begin{bmatrix} 0.1 \\ 0.1 \\ 0 \\ 0 \end{bmatrix} puMW$$

Each area's load is the sum of the local DISCOs demand, i.e. ΔP_{L1}=0.2 and ΔP_{L2}=0.

***Case 2**:* All the DisCo's contract with the GenCo's for power as per the following DPM:

$$DPM = \begin{bmatrix} 0.5 & 0.25 & 0 & 0.3 \\ 0.2 & 0.25 & 0 & 0 \\ 0 & 0.25 & 1 & 0.7 \\ 0.3 & 0.25 & 0 & 0 \end{bmatrix}, DISCO = \begin{bmatrix} 0.105 \\ 0.045 \\ 0.195 \\ 0.055 \end{bmatrix} puMW$$

It is assumed that each DisCo demands 0.1puMW power from GenCos as defined by *cpf*s in DPM matrix and each GenCo participates in AGC by following *apf*s: apf_1=0.75, apf_2=0.25, apf_3=0.5, apf_4=0.5.

***Case 3**: Contract violation*: It may happen that a DisCo violates a contract by demanding more power than that specified in the contract. This excess power is not contracted out to any GenCo. This uncontracted power must be supplied by the GenCos in the same area as the DisCo. It must be reflected as a local load of the area but not as the contract demand. So, consider Case 2 again with a modification that DisCo1 demands 0.1puMW of excess power, which is reflected now in ΔP_{L1}.

The time responses of the system are simulated and the signals are sampled at 10 Hz. The system is also simulated with the Donde et. al. settings [3] for Case 1 with integral control. The results are presented in Figs. 6-8 for the Cases 1-3 respectively and show the effects of the load change: area frequency deviations, actual power flow on the tie line (e.g. in a direction from area I to area II for Case 1), and the generated powers of the various GenCos following the step change in the load demands of the DisCos. Visually the GA-tuned system has the fastest frequency response. The frequency deviation in each area goes to zero in the steady state. Also, in the steady state, generation of a GenCo matches the demand of the DisCos in contract with it. Due to lack of space, only Case's 3 objective function values through GA generations are shown in Fig. 5. From the same figure, it is seen that a PI controller gives the minimum value of objective function. Table 1 validates the latter for the other two Cases. The same Table gives the optimum controller gains (K_i) or (K_p, K_i) as well as the values of the frequency biases for the two areas obtained by the application of the GA along with the corresponding objective function value. For Case 1 with integral control it can be seen that GA performs better that the gradient type Newton algorithm used in [3]. Simulations were made also for ID and PID controllers (their results are not shown here). It is found that ID controllers seem to fail to come to steady state easily (but they pertain small oscillations around the nominal value i.e. Δf=0), while PID controller act too fast to the generator inputs (this is not desirable for the wear and tear of the machines) and also exhibit very fast oscillations. Thus, PI controllers seem to be the better choice for the system under study especially when they are to be tuned properly. Another interesting thing to observe from Figs. 6-8 is that the quantities that are involved to the objective function (i.e. Δfs and ΔP_{tie}), have the fastest response when the PI controllers are applied, but the rest quantities (i.e. the generated powers of the GenCos) have the fastest response when the integral controllers are applied. This leads to the conclusion that the choice of the objective function is crucial and the behavior of the tuned system is directly depended on it.

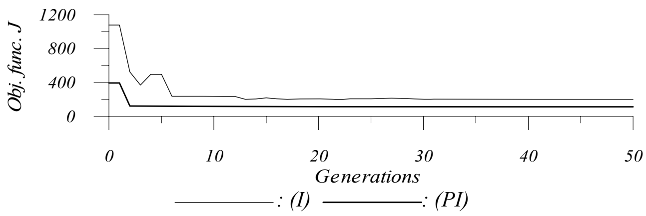

Fig. 5. *Objective function values through GA generations for Case 3.*

Table 1. Controller (integral or proportional integral.) gains, frequency biases and fitness function values obtained by GA.

	Case 1			*Case 2*		*Case 3*	
	I	(Donde [3])	***PI***	***I***	***PI***	***I***	***PI***
Controller Gains (K_i) or (K_p, K_i)	0.7715	0.6588	-0.7485, 1.2625	0.1834	0.5639, 0.3449	1.010	0.6692, 0.5122
Freq. Bias (B)	0.4078	0.439	0.2631	2.5022	1.8603	0.5054	1.7065
Obj. func. Value (J)	76.4868	78.0542	**55.8181**	118.7111	**67.0767**	197.6789	**113.9435**

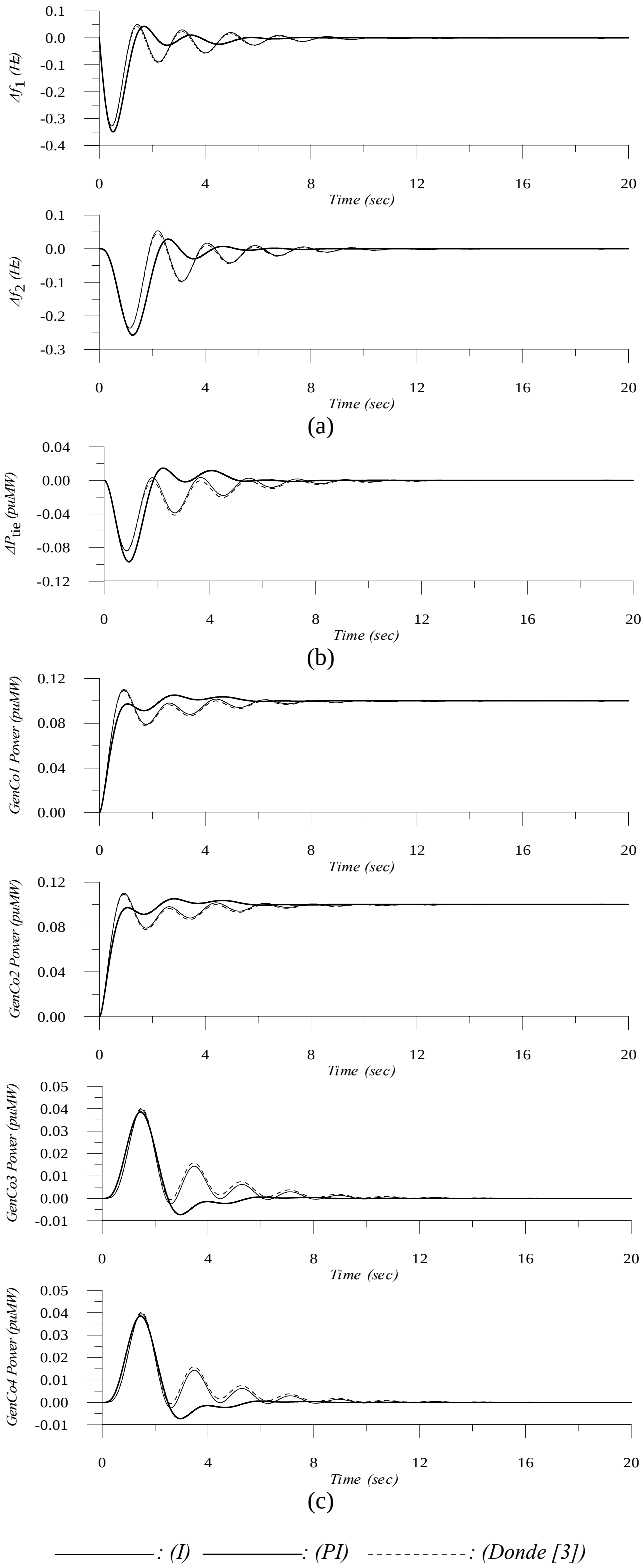

Fig. 6. *Transient system response curves for Case 1: (a) frequency deviations, (b) Tie line power, (c) Generated power.*

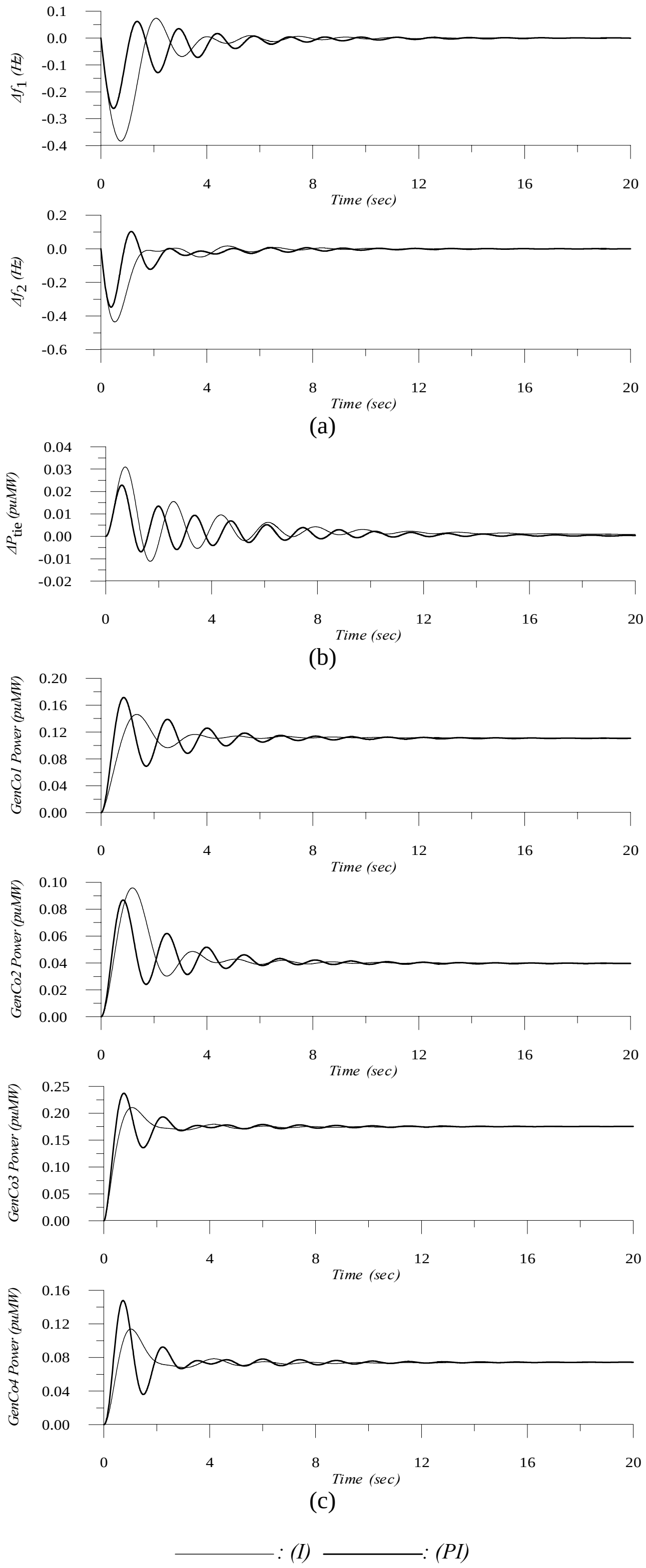

Fig. 7. *Transient system response curves for Case 2: (a) frequency deviations, (b) Tie line power, (c) Generated power.*

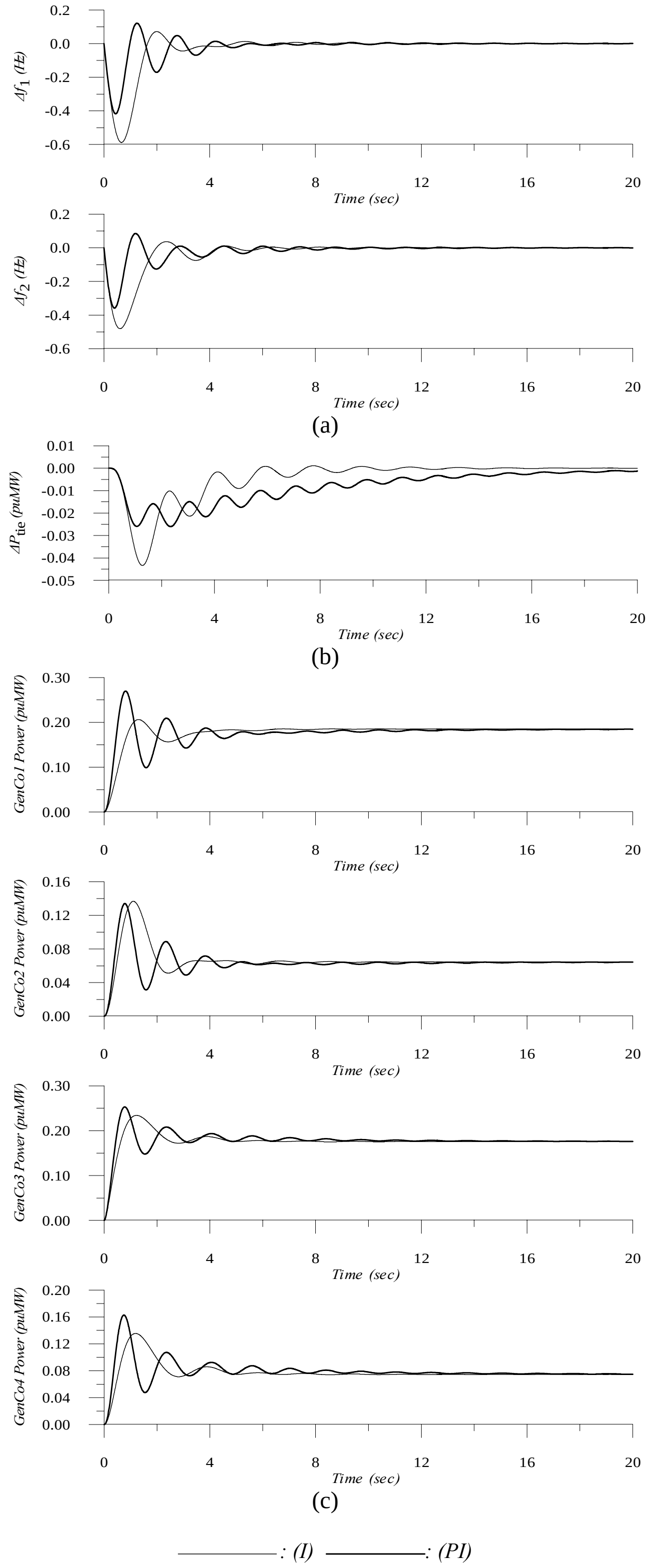

Fig. 8. *Transient system response curves for Case 3: (a) frequency deviations, (b) Tie line power, (c) Generated power.*

5 Conclusions

The modified AGC scheme in a deregulated environment includes contract data and measurements. There are various possible types of contracts combinations. In the new restructured environment, GenCos sell power to various DisCos at competitive prices, and the minimization of the total cost in this open market, is one of the most important aspects. In this context, the tuning of area controllers in an AGC deregulated system is discussed and applied. In this tuning process, GAs is a valuable tool and provide quite easily the best answers for such a kind of problem. Controller gains and frequency biases are obtained for integral and PI type controllers. The responses of the tuned system with both types exhibit better performances compared to other ones found in literature. It is also seen that the choice of the objective function is important and affects the behavior of the system. Further work would include multi area systems, new controller structures as well as different power system characteristics i.e. hydro and diesel units for the GenCos.

Appendix (Power System Data):

$P_{r1}=P_{r2}=2000MW$, $f_o=60Hz$, $K_{ps1}=K_{ps2}=120Hz/puMW$, $T_{ps1}=T_{ps2}=20sec$, $K_{t1}=K_{t2}=K_{t3}=K_{t4}=0.5$, $T_{t1}=T_{t2}=T_{t3}=T_{t4}=0.3sec$, $K_{g1}=K_{g2}=K_{g3}=K_{g4}=1$, $T_{g1}=T_{g2}=T_{g3}=T_{g4}=0.08sec$, $R_1=R_2=R_3=R_4=2.4Hz/puMW$, $T_{12}=0.545puMW$, $a_{121}=a_{122}=-1$, $B_o=0.425puMW/Hz$, ,

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