Comparison of Various Load Frequency Control Schemes in Restructured Power System Environment

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Abstract. This paper presents comparison of performances of secondary controllers like Integral (I), Proportional-Integral (PI), Integral-Derivative (ID), Proportional-Integral-Derivative (PID) and Integral-Double Derivative (IDD) as load frequency control scheme. The controllers have been tested on two equal areas thermal power system with non-reheat turbines in the presence of nonlinearity i.e. generation rate constraint (GRC) of 3% per minute. The disco participation matrix (DPM) is considered for various power transactions between Genco and Discos in both areas. A well-known optimization algorithm i.e. genetic algorithm (GA) is used to determine the optimal parameters of different controllers. Three cases i.e. load perturbation in one area only, load perturbation in both areas and more demand asked by Disco than the contract have been considered to check the response of controllers. Comparative analysis of the results obtained for all three cases show that Proportional-Integral-Derivative (PID) controller provides better performance than other controllers in terms of settling time.

Keywords: Load Frequency control; bilateral contracts; deregulation; Genetic algorithm; power system

1. INTRODUCTION

An important concern about complex power system is to maintain different kinds of balances such as load-generation balance, and flows such as scheduled and actual tie line flows. Since system conditions are always altering it would be impractical to control these balances. The objective of LFC is to maintain nearly constant frequency along with regulation of tie-line flows [1-3]. The structure of power system is now becoming complex, consequently, the growth of more specialized industries for generation (Genco), transmission (Transco) and distribution (Disco), independent system operator (ISO), under open market system (deregulation) has become conceivable. The estimation of LFC in a deregulated environment has been perused in [4]. In addition, a detailed review of the subject and the simulation of an LFC system after deregulation is presented. Generally, regulation of frequency in electrical grid is obtained by power balance between generation and demand through load pattern [5]. The Gencos regulate their output power as the load demand varies to keep power system at balance. If the Gencos are at their full capacity an additional load demand will fluctuate the frequency.
It is seen from literature survey that power system performance depends on control structure and fitness function. Therefore, it is always welcome to propose and apply new high performance optimization algorithms to real-world issues. In LFC, to maintain equilibrium, the controller plays an important role. Therefore, many methods have been used in literature, such as classical, stable, adaptive, optimal, nonlinear, modern, etc. Additional control systems are also used to implement LFC controllers based on various soft computing methods such as ant colony (ACO), GA, PSO, HS, ANN, Fuzzy etc. [6-10]. A conventional system comprising thermal/hydro or mixture of both has been studied in the past. The controller like I, PI and PID are popular among researchers due to their merits like simple construction, easy implementation, good performance etc. The effectiveness of these control approaches have successfully been seen in many areas from power system to chemical system.

Nowadays, power system is being change from conventional to deregulated environment because of merits of deregulated ones. However, the stability of power system in this deregulated environment is a point of prime concern. This increases the role and responsibility of the control approaches are being used in power system [11-13]. The changed environment requires optimal control scheme, since it has been shown that conventional optimization technique is definitely not preferred when the number of parameters to be optimized is high. Therefore, optimization technique like GA, BBBC, ICA, HS etc. has gained popularity and been successfully applied on various areas of engineering. The objective of this study is to compare and check the performance of the I, PI, ID, PID, and IDD controllers on a deregulated power system considering nonlinearity like GRC. Three cases have been considered to check the performance of mentioned controllers. The optimal parameters of controllers have been determined using GA.

2. PROBLEM FORMULATION

A two equal areas thermal power system with nonlinearity like GRC of 3% per minute has been considered as a test system to check the performance of the designed controllers. Both areas have 2 Gencos and 2 Discos each. The scheduled tie-line power of -0.05 (area-2 to area-1) pu has also been taken to simulate all three cases. As it is known that with the introduction of deregulation, conventional power system is being through many reforms. The task of frequency control become more important in this scenario. Nowadays, a Disco is free to has power contract from Genco of its area or from another area and this way of power transaction is known as bilateral trading which is implemented by Disco participation matrix (DPM) [9-13].

A controller is used to eliminate area control error given in (1).

\[ \text{ACE}_i = B_i \Delta F_i + \Delta \text{Ptie}_i \]  

In deregulated environment, different transactions like poolco, bilateral, and combination of both are being used for power transactions. Bilateral transactions have an effect on tie-line power and modifies as (2).

\[ \Delta \text{Ptie}_{i,\text{new}} = \Delta \text{Ptie}_i + \sum_{j=1}^{n} D_{ij} + \sum_{j=1}^{n} D_{ji} \]  

Where \( n \)=total areas, \( D_{ij} \)=Disco’s demand (area-j) to the Gencos (area-i), \( D_{ji} \)= Disco’s demand (area-i) to the Gencos (area-j), \( \Delta \text{Ptie} \)=tie-line flow variation without bilateral contract.

This variation in tie-line flow modifies the existing ACE as given in (3),

\[ \text{ACE}_i = B_i \Delta F_i + \Delta \text{Ptie}_{i,\text{new}} \]  

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3. CONTROL SCHEMES

This section explains structure and optimization algorithm to obtain optimal parameters of different controllers. For instances let us consider the PID control scheme. The most common structure of a PID is given in (4-5) and represented in Figure 2.

\[ U(t) = K_P \cdot E(t) + K_I \cdot \int E(t) + K_D \cdot \frac{E(t)}{s} \]  

(4)

Another well-known form of PID controller is

\[ G_{PID}(s) = K_P + K_I \cdot \frac{1}{s} + K_D \cdot s \]  

(5)

Where, \( K_P \), \( K_I \), and \( K_D \) = PID parameters.

![Figure 2. Block diagram representation of PID control scheme.](image)

The other controllers like ID, I, PI, IDD can be represented similarly as given in (4-5). Figure 3 shows IDD control scheme used in the paper.

![Figure 3. Simulation representation of IDD control scheme.](image)

For effective performance of each control schemes, the parameters should be obtained optimally, therefore, in this work GA algorithm is used to decide parameters by minimizing fitness function, given in (6).

\[ F = \frac{1}{m} \sum_{i=1}^{m} [(ACE_i)^2] = \frac{1}{m} \sum_{i=1}^{m} [(B_i \cdot \Delta f_i + \Delta P_{tie_{i-error}})^2] \]  

(6)

One controller been taken in each control area.

**Optimization algorithm:** GA is a search technique that simulates the process of biological evolution. An overview of the steps the algorithm implements is given in the following flowchart. By repeatedly modifying a population of candidate solutions before an optimal solution is found, it mimics evolution in nature. With a randomly chosen initial population, the GA evolutionary cycle begins. Population changes occur by fitness based selection processes, and mutation and crossover...
modification. Applying selection and modification results in a population with a greater proportion of enhanced solutions. The evolutionary cycle continues until the current population generation seeks an appropriate solution or certain regulatory limits are surpassed, such as the number of generations. Basic structure of GA is given in Figure 4.

4. SIMULATION AND RESULTS

The control schemes have been designed for two-area LFC scheme based on Figure 1. In both the areas and their governor-turbine units are identical. Two Gencos (G1 and G2 in area-1 and G3 and G4 in area-2) and two Discos (D1 and D2 in area-1 and D3 and D4 in area-2) are considered in each area.

4.1 Case 1: Load perturbation in area-1 only

Controller is tested against a load perturbation of 0.2 pu load in one area, [area-1 (0.1pu/D1 and 0.1pu/D2)], [area-2 (0.0 pu/D3 and 0.0/D4)]. The parameters of 2-area power system, and GA parameters are considered as given in appendix.

To follow the loads perturbation, the change in Gencos due to bilateral transactions can be determined as

\[
(\Delta P_i) = \sum_j \text{cpf}_{ij} \Delta P_{ij} \quad i=1,2
\]

Where, \(\Delta P_{ij}\) = Load change of \(j\)th Disco and \(\text{cpf} = \) elements of the DPM.

For the considered case, change in the power of \(i\)th generator, responding to bilateral transaction can be written as,

\[
(\Delta P_i) = \text{cpf}_{i1} \Delta P_{i1} + \text{cpf}_{i2} \Delta P_{i2} + \text{cpf}_{i3} \Delta P_{i3} + \text{cpf}_{i4} \Delta P_{i4} \quad \text{for } i=1,2
\]

Therefore, the change in Gencos in area-1, due to bilateral transactions can be determine as,

- \((\Delta P_{G1\text{-area1}}) = 0.5 \times 0.1 + 0.5 \times 0.1 + 0 \times 0 + 0 \times 0 = 0.1 \text{ pu}
- \((\Delta P_{G2\text{-area1}}) = 0.5 \times 0.1 + 0.5 \times 0.1 + 0 \times 0 + 0 \times 0 = 0.1 \text{ pu}

The change in Gencos of area-1 are shown in Figure 5. It is seen that Gencos are setting to their net change in area-1.

![Figure 4. Basic flow of GA.](image)

![Figure 5. Gencos response in area-1.](image)
Similarly, in area 2: G3 and G4 have bilateral contracts with Disco of area-1 and Discos of area-2. However, the load perturbation occurs in area-1, therefore, the Gencos in area-1 will change their generation. No net change in generation of Gencos in area-2 means G3 and G4 will settle down to zero at steady state, as given in Figure 6. The tile-line power deviation is given in Figure 7.

\[
(\Delta P_{G3-\text{area2}}) = 0 \times 0 + 0 \times 0 + 0 \times 0 + 0 \times 0 = 0 \text{pu} \\
(\Delta P_{G4-\text{area2}}) = 0 \times 0 + 0 \times 0 + 0 \times 0 + 0 \times 0 = 0 \text{pu}.
\]

![Figure 6. Gencos response in area-2](image1.png)

![Figure 7. Response of Tie-line power flow.](image2.png)

The load perturbation also affects power flow through tie-line, which can be calculated using (8).

\[
\Delta P_{\text{tie}} = \sum_{i=1}^{2} \sum_{j=3}^{4} c_{ij} \Delta P_{L_i} - \sum_{i=1}^{2} \sum_{j=1}^{4} c_{ij} \Delta P_{L_j} = 0 \text{pu}
\]

(8)

On a load perturbation, speed of Machine gets affected which intern affect the frequency. This deviation in frequency must settle down to the scheduled value in a shortest time span for stability point of concern. To bring back frequency at its original value is the prime job of a good control approach. The frequency deviation response for this case is given in Figure 8.

![Figure 8(a) and (b). Response of frequency deviation in area-1 and in area-2.](image3.png)

**4.2 Case2: Load perturbation in both areas**

This case considers load perturbation in both areas for which the performance of designed control schemes has been checked. It is considered that a load of 0.2 pu occurs in area-1 as well in area-2. Different transactions between Gencos and Discos have been considered as given in the DPM.

\[
\begin{array}{cccc}
D1 & D2 & D3 & D4 \\
G1 & 0.5 & 0.25 & 0 & 0.3 \\
G2 & 0 & 0.25 & 0 & 0 \\
G3 & 0 & 0.25 & 0 & 0.7 \\
G4 & 0.3 & 0.25 & 0 & 0 \\
\end{array}
\]

To response load perturbation, Gencos in both areas must increase their generation as per equation given in (7).

\[
(\Delta P_{G1-\text{area1}}) = 0.07418 \text{pu}. \quad (\Delta P_{G2-\text{area1}}) = 0.07582 \text{ pu}.
\]

Similarly, Gencos in area-2 will increase their generation as
\((\Delta P_{G3-\text{area2}}) = 0.125 \text{ pu}\).

\((\Delta P_{G4-\text{area2}}) = 0.125 \text{ pu}\).

Further, the same is represented in Figure 9.

\[
\sum_{i=1}^{4} \sum_{j=3}^{4} \Delta P_{\text{tie}} = c_{\text{pf}} \sum_{i=1}^{3} \Delta P_{L_i} - c_{\text{pf}} \sum_{i=1}^{4} \Delta P_{L_i} = -0.05 \text{ pu}
\]  \hspace{1cm} (9)

The tie-line power will settle down at the value and same can be represented as given in Figure 10.

4.3 Case3: Load perturbation in both areas with an extra demand of 0.1 pu in area-1

This case considers load perturbation in both areas with a consideration that in area-1, an extra demand of 0.1 pu has also been asked. This extra demand is not in contract given in DPM. The
generators in area-1 will take care of this extra demand asked in area-1, which deviates frequency. Therefore, change in generation of area-1 Gencos can be written as given in Figure12.

\[ (\Delta P_{G1,\text{area1}}) = 0.1229 \text{ pu}, \quad (\Delta P_{G2,\text{area1}}) = 0.1271 \text{ pu}. \]

It is evident from result that this extra demand has been successfully been taken care by area-1 Gencos. Similarly, Gencos in area-2 will increase their generation i.e. same as in case 2.

\[ (\Delta P_{G3,\text{area2}}) = (\Delta P_{G4,\text{area2}}) = 0.125 \text{ pu}. \]

The tie-line power will settle down at the same value as was in case 2. The same is represented in Figure 13.

**Figure 12 (a) and (b).** Gencos response in area-1 and area-2.

**Figure 12(c).** Gencos response in area-2.

The response for frequency deviation is given in Figure 14. It is seen that at steady state frequency deviation in both areas are going to settle down at the scheduled value using the given approaches.

**Figure 14 (a) and (b).** Response of frequency deviation in area-1 and area-2.
It is witnessed from the results that PID provides better performance than others. The performance has also been compared in terms of undershoot/overshoot and settling time as given in Table 1, which shows that the PID controller better given in Table 1, which shows that the PID controller better.

| Case 1 | (I/ID/IDD/PI/PID) | 230 | 0.0144/0/0/0.084/0 | - |
|---|---|---|---|---|
| Case 2 | (I/ID/IDD/PI/PID) | 280 | 0.13/0/0/0.065/0.07 | - |
| Case 3 | (I/ID/IDD/PI/PID) | 300 | 0.14/0/0/0.035/0.04 | - |

5. CONCLUSION

This paper discusses frequency-related issues in a restructured multi-area power system in the presence of nonlinearity like GRC. An investigation of LFC problems considering mutual transactions has been carried out with different controllers like I, ID, IDD, PI, PID in two-area (thermal) power system. Optimum parameters of controller area calculated using GA algorithm. Three cases have been considered to check the performance of all the controllers. Further, a comparative study has been carried among the performance of all the controllers. The simulation shows that the designed control schemes are successful and satisfy LFC scheme, but, PID controller gives better performance than others. It is observed that frequency error at steady state is zero in all cases, using PID controller in a smaller settling time than others. Therefore, PID controller can be used as LFC scheme in a deregulated power system.

REFERENCES

[1] V. Donde, M A. Pai, IA. Hiskens 2001 Simulation and optimization in an AGC system after deregulation. IEEE Transactions on Power Systems 16, 481-9.
[2] R. D. Christie and A. Bose 1996 Load frequency control issues in power system operations after deregulation. IEEE Transactions on Power Systems 11, 1191-200.
[3] S.K. Pandey, S.R. Mohanty and N. Kishore 2013 A literature survey on load frequency control for conventional and distribution generation power systems. Renewable and Sustainable Energy Reviews 25, 318–334.
[4] D. K. Chaturvedi, PS. Satsangi and PK. Kalra 1999 Load frequency control: a generalized neural network approach. Electrical Power & Energy Systems 21, 405-15.
[5] C.S. Chang and W. Fu 1997 Area load frequency control using fuzzy gain scheduling of PI controllers. Electric Power System Research 42, 142-52.
[6] H. Gozde and M. C. Taplamacioglu 2011 Automatic generation control application with craziness based particle swarm optimization in a thermal power system. International Journal of Electrical Power and Energy Systems 33, 8–16.
[7] S. K. Aditya and D. Das 2003 Design of load frequency controllers using genetic algorithm for two area interconnected hydropower system. Electric Power Component System 31, 81-94.
[8] Z.W. Geem, J. H. Kim, and G. V. Loganathan 2001 A New Heuristic Optimization Algorithm: Harmony Search. Simulation 76, 60-68.
[9] N. Kumar, B. Tyagi, and V. Kumar 2017 Multi-area deregulated automatic generation control scheme of power system using imperialist competitive algorithm based robust controller. IETE journal of Research-Taylor & Francis 64,528-537.
[10] N. Kumar, B. Tyagi, and V. Kumar 2016 Multi Area AGC scheme using Imperialist Competition Algorithm in Restructured Power System. Applied soft Computing-Elsevier 48, 160-168.
[11] N. Kumar, B. Tyagi, and V. Kumar 2016 Deregulated multiarea AGC scheme using BBBC-FOPID controller. Arabian journal of science and Engineering-Springer 42, 2641-2649.
[12] N. Kumar, B. Tyagi, and V. Kumar 2017 Application of Fractional Order PID Controller for AGC under Deregulated Environment. International Journal of Automation and Computing-Springer 15, 84-93.
[13] N. Kumar B. Tyagi, V. Kumar 2015 Optimization of PID parameters using BBBC for multi-area AGC scheme in deregulated power system, Turkish Journal of Electrical Engineering and Computer Science 24, 4105-4116

**Appendix**

**Table A.1:** Two-area power system parameters.

| Parameters                | Value |
|---------------------------|-------|
| Time constant /Governor   | 0.08  |
| Time Constant /Power system | 24   |
| Gain Constant/Power system  | 120  |
| Time Constant/Turbine     | 0.3   |
| Speed regulation          | 2.4   |
| Frequency Bias            | 0.425 |
| Synchronizing constant    | 0.545 |

**Table A.2:** GA Parameters.

| Parameter    | Value |
|--------------|-------|
| Population   | 50    |
| Size         |       |
| Fitness      | Rank  |
| Scaling      |       |
| Selection    | Stochastic |
| Crossover    | Constraint dependent |
| Mutation     | Constraint dependent |
| Variable     | 03    |