AGC of an Interconnected Power System under Deregulated Environment using GA-tuned Fuzzy Logic Controller

Vishal Jain1*, Devender Saini1 and K. N. Dinesh Babu2

1UPES, Dehradun - 248007, Uttarakhand, India; vishal_dehradun@yahoo.com, dksaini@upes.ddn.ac.in
2General Electric, Hyderabad, India; dineshbabukn@gmail.com

Abstract

Objectives: To design a Fuzzy Controller with knowledge of the system for AGC under Deregulated environment. Genetic Algorithm (GA) is proposed to be used to fine-tune the response of FLC by optimizing its gain through minimization of an ITAE based objective function. Methods/Statistical Analysis: Performance of the system is determined using distinct scenario of DISCO participation. The simulation is carried out on a two area model of AGC using MATLAB SIMULINK. Sensitivity analysis is carried out by varying various model parameters. Comparison between the optimised-FLC (GAFLC), hand-tuned FLC and PI controller is tabulated. Findings: It is revealed from the simulation results and the comparison table that GAFLC shows a paramount improvement in the transient response specifications in contrast to a PI and Fuzzy (hand-tuned) controller. Furthermore the GAFLC is able to confine the response within acceptable range even under the parametric changes, thus making the controller robust. The proposed work is novel in that; it takes into account the parametric variations in the system under deregulation. The controller thus designed is intelligent and reduces significant time and effort in tuning the fuzzy controller and at the same time able to arrest the parametric disturbances occurring in the system. Application/Improvements: The GA is effectively utilised as an optimisation tool to make the controller intelligent and thus can be implemented for the use in modern power system.

Keywords: AGC, Deregulation, Disco-Participation, Fuzzy, GAFLC, Intelligent

Nomenclature

| Abbreviation | Description                  |
|--------------|------------------------------|
| ACE          | Area Control Error           |
| FLC          | Fuzzy Logic Controller       |
| Psize        | Size of Population           |
| Pm           | Mutation probability         |
| Pc           | Crossover probability        |
| Tg           | Governor time constant       |
| Tp           | Generator time constant      |
| Tt           | Turbine time constant        |
| Cpf          | Contract participation factor|

1. Introduction

Power System has various utilities which are bound together completely through a tie-line. With changing load conditions, it is required to keep the frequency and tie-line power exchange1 to its nominal value. Any variation in these values is undesirable. Thus an Intelligent controller2 having quick response is essential to keep the frequency close to normal, which confines the parametric changes in the system to the tolerable range, as compared to other traditional controllers viz. Integral, PI and PID.
AGC of an Interconnected Power System under Deregulated Environment using GA-tuned Fuzzy Logic Controller

The writing literature on AGC in traditional and Deregulated situations and etc. has been applied for AGC, to surmount the shortcomings of existing controls. A fuzzy system can be successfully used, but since it is based on trial and error, the proper fuzzy parameters (input and output scaling factors, fuzzy rules and mfs) cannot be chosen. By and large these parameters are chosen using expert knowledge and may not be the best possible ones. Selection of the optimal parameters may enhance the performance of the FLC to a larger extent by employing suitable intelligent techniques. Genetic Algorithms has emerged as a very powerful optimisation tools in the recent years. Considering the above, the input and output gains of FLC are optimised using Genetic Algorithm (GA) for the two area system under deregulation. The supremacy of the projected GA optimised FLC has been shown by comparing the results with the hand-tuned FLC and conventional PI controller.

2. Restructured Power System

Conventionally, the electric power trading is managed by Vertically Integrated Utilities (VIUs). These utilities deliver power to consumers at regulated tariff, as they have their own generation, transmission and distribution systems.

In a Deregulated environment the VIUs do not exist, instead, it has a System Operator (SO), distribution, generation and transmission companies termed as DISCOs, GENCOs and TRANSCOs respectively. Operation of AGC has to be reformulated but their basic idea remains same.

In the new scenario, DISCOs are free to purchase power from any GENCOs therefore demand on each of GENCOs is changed continuously, so it becomes a difficult task to match the generation and demand. Because of slow turbine speed governing system it becomes a challenge to control the frequency under varying load conditions of deregulated power system. The DISCO Participation Matrix (DPM) is used to realize the numerous contracts that are implemented by the GENCOs and DISCOs.

Figure 1 illustrates the distribution of GENCOs and DISCOs in each area. The related DPM is shown in Table 1.

Each entry in Table 1 represents a part of entire load contracted by a DISCO (column) toward a GENCO (row). DPM depicts the participation of a DISCO in a contract with a GENCO and hence the “DISCO participation matrix”.

![Figure 1. Configuration of restructured power system.](image)

| DISCO | GENCO |
|-------|-------|
| DISCO1 | GENCO1 |
| DISCO2 | GENCO2 |
| DISCO3 | GENCO3 |
| DISCO4 | GENCO4 |

3. AGC Model Representation

The MATLAB SIMULINK model of AGC system under restructured scenario is depicted in the Figure 2. A case is considered with an equal participation of the GENCOs of each area in AGC. Load changes are assumed to occur only in area 1. Thus only DISCO1 and DISCO2 has a load demand of 0.08 pu MW each, i.e., ΔPL1 = ΔPL2 = 0.08 pu MW, ΔPL3 = ΔPL4 = 0. Now for this scenario the DPM is taken as:

\[
\text{DPM} = \begin{bmatrix}
0.50 & 0.50 & 0 & 0 \\
0.50 & 0.50 & 0 & 0 \\
0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 \\
\end{bmatrix}
\]

The implementation of the Disco Participation matrix is illustrated in Figure 3.
3.1 Design of Fuzzy Logic Controller

ACE and d/dt (ACE) are the two inputs to the fuzzy controller as shown in Figure 4. The rule base used for the FLC is described in Table 2. The FLC gains are initially taken so that the different input and output variables glide within their respective Universe of Discourse.

After the formation of the SIMULINK model of AGC, Fuzzy controller is designed with symmetrical MFS using fuzzy logic tool box. The gains of the FLC1 and FLC2 are chosen so as to get the desirable response.

Five membership functions (NL, NS, Z, PS and PL ) are defined for the two inputs and one output variable in Figure 5.

3.2 Design of Objective function

The objective function generally used for optimizing the gains of FLC is computed with a performance index. Various performance measures are used in the design of control problems. It has been demonstrated in earlier paper that Integral of time multiplied absolute error (ITAE) is a better choice. In this paper ITAE method is used for computing the objective function.

\[
J = \text{ITAE} = \int_0^T (|\Delta F_1| + |\Delta F_2| + |\Delta P_{\text{tie}}|).t \, dt
\]

\(\Delta F_1\) = Frequency change in area 1. \(\Delta F_2\) = Frequency change in area 2. 
\(\Delta P_{\text{tie}}\) = Tie Line Power change. \(T\) = Simulation time.

3.3 Chromosome Length

In this paper, the gains factors of FLC are optimized using GA to improve its performance. The chromosome structure is decided as per the sets of parameters of gains. There are two gains each in the FLC of Area 1 (\(K_a, K_p\)) and Area 2 (\(K_a, K_p\)), thus the chromosome has length given by

\[L = [2+2] = 4.\]

GA parameters chosen: Popsise = 30; lchro = 4; \(P_c = 0.6; P_m = 0.003.\)
4. Result and Discussions

The two area deregulated interconnected system represented in Figure 2 is simulated with Conventional PI controller and Fuzzy Controller with and without Genetic Algorithm technique. Separate GA program is run for determining the optimal parameters of FLC gains. Some good results are produced in various generations (Fitness = 0.8787 Fitness = 0.88788). As per the termination criterion GA produced the best result in 36 generations corresponding to the minimum fitness function. The optimal parameters of the FLC gains are shown in Table 3.

Figure 6 shows the response comparison of frequency change in Area 1 ($\Delta f_1$), Area 2 ($\Delta f_2$) and the tie-line power change ($\Delta P_{tie}$) obtained with conventional PI, Hand tuned FLC and GA optimised FLC. It is apparent from Figure 6 that the settling time ($T_s$) undershoots ($U_{sh}$) and overshoots ($O_{sh}$) in $\Delta f_1$, $\Delta f_2$ and $\Delta P_{tie}$ obtained with the proposed GAFLC are less as compared to PI and Hand tuned FLC.

Table 4 illustrates the transient response specification revealing undershoot ($U_{sh}$), overshoot ($O_{sh}$) and settling time ($T_s$) (with 0.005% tolerance band) of $\Delta f_1$, $\Delta f_2$ and $\Delta P_{tie}$ for different controllers. It is visible from the data that the paramount system performance is achieved with the intelligent GAFLC.

4.1 System with Parametric Disturbances

Sensitivity analysis is performed on the system with parametric variation within tolerable range. System parameters ($Tg$, $Tr$, $Tt$, $TP$) are varied in steps of 25% from -50% to +50% of their nominal values. Figure 7 portrays the response of $\Delta f_1$, $\Delta f_2$ and $\Delta P_{tie}$ under different parametric changes. Table 5 shows the performance indices under different parametric changes. It is observed that the GAFLC arrests the parametric disturbances well within the tolerable limits with the same set of optimal gains, thus addressing the problem of load frequency control.

![a) Frequency deviation in area 1.](image)

![b) Frequency deviation in area 2.](image)

![c) Deviation in tie-line power.](image)

**Figure 6.** Response comparison of PI, Hand-tuned FLC and GAFLC.
Table 3. Optimised GAFLC parameters

| Controller   | Objective Function Values (IATE) | K1     | K2     | K3     | K4     |
|--------------|----------------------------------|--------|--------|--------|--------|
| GA FLC       | 0.9625                           | -0.0482| 3.9984 | -0.0085| 2.0494 |
| FLC HAND TUNED| 1.823                            | -0.02  | 3.6    | -0.05  | 0.5    |

Table 4. Transient response specifications of $\Delta f_1$, $\Delta f_2$, and $\Delta P_{tie}$ for nominal system parameters

| Controller          | $\Delta f_1$ | $\Delta f_2$ | $\Delta P_{tie}$ |
|---------------------|--------------|--------------|------------------|
|                     | $U_{sh}$ (x10$^{-3}$) | $O_{sh}$ (x10$^{-3}$) | $T_s$ (in sec) | $U_{sh}$ (x10$^{-3}$) | $O_{sh}$ (x10$^{-3}$) | $T_s$ (in sec) |
| GAFLC               | -34.34       | 13.41        | 2.8             | -7.731          | 0             | 4.5             | -4.934          | 0             | 2.08             |
| FUZZY (Hand Tuned)  | -44.94       | 17.25        | 5.03            | -11.39          | 0             | 7.3             | -8.139          | 0             | 7.6              |
| PI                  | -52.73       | 40.13        | 11.9            | -17.1           | 18.43         | 11.29           | -6.487          | 8.192         | 27.5             |

Figure 7. System response with different parametric variations.

a) Frequency deviation in area 1.

b) Frequency deviation in area 2.

c) Tie line power deviation.
5. Conclusion

In this study, Fuzzy Logic Controller with and without GA is implemented under deregulation for a two area AGC. A contrast of the simulation outcomes with conventional PI controller is made. The evaluation shows that the proposed intelligent controller is faster and has an enhanced dynamic response. Furthermore, sensitivity analysis carried out by altering the nominal parameters of the system over a broad range, depicts the robustness of the proposed controller.

Appendix A1.
Nominal Parameters of 2 area Reheat system are \( R_1 = R_2 = 2.4 \text{ Hz/p.u M.W} \), \( B_1 = B_2 = 0.425 \text{p.u M.W} \), \( f = 60 \text{ Hz} \), \( T_g = 0.08s \), \( T_i = 10s \), \( T_e = 0.3s \), \( K_i = 0.5 \), \( K_p = 120 \text{ Hz/p.u M.W} \), \( \Delta P_{d1} = 0.04 \).

6. References

1. Elgerd OI. Electric energy systems theory: An Introduction. 1971. p. 564.
2. Patel RN, Sinha SK, Prasad R. Design of a robust controller for AGC with combined intelligence techniques. International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering. 2008; 2(9):1951–7.
3. Dash P, Saikia LC, Sinha N. Comparison of performances of several Cuckoo search algorithm based 2DOF controllers in AGC of multi-area thermal system. International Journal Electronic. Power Energy System. 2014 Feb; 55:429–36.
4. Saikia LC, Nanda J, Mishra S. Performance comparison of several classical controllers in AGC for multi-area interconnected thermal system. International Journal Electronic Power Energy System. 2011; 33(3):394–401.
5. Panda G, Panda S, Ardil C. Automatic generation control of interconnected power system with generation rate constraints by hybrid neuro fuzzy approach. World Acad Sci Eng Technol. 2009; 52:543–8.
6. Debbarma S, Saikia LC, Sinha N. Robust two-degree-of-freedom controller for automatic generation control of multi-area system. Int J Electr Power Energy Syst. 2014; 63:878–86.
7. Hou G, Lou R, Zhang J, Zhang Q, Fan C. T-S model based Fuzzy Logic Controller for AGC system after deregulation considering DPM. Chinese Control and Decision Conference, CCDC 2009; 2009. p. 2231–6.
8. Karnavas YL. AGC tuning of an interconnected system after deregulation using Genetic Algorithms. Proceedings of the 5th WSEAS Int Conf on Power Systems and Electromagnetic Compatibility; 2005. p. 218–23.
9. Kaur R, Kaur J. PID-controller-based-AGC-under-two-area-deregulated-power-system.doc. Int J Sci Eng Res. 2015; 6(6):666–73.
10. Kumar N, Tyagi B, Kumar V. Deregulated AGC scheme using dynamic programming controller. Eighteenth National Power Systems Conference (NPSC); 2014. p. 1–6.
11. Roy R, Ghoshal SP, Bhatt P. Evolutionary computation based four-area automatic generation control in restructured environment. 2009 International Conference on Power Systems; 2009. p. 1–6.
12. Chown GA, Hartman RC. Design and experience with a Fuzzy Logic Controller for Automatic Generation Control (AGC). Proc 20th Int Conf Power Ind Comput Appl; 1997.
13. Bhongade S, Gupta HO, Tyagi B. Artificial neural network based automatic generation control scheme for deregulated electricity market. Conference Proceedings IPEC; 2010. p. 1158–63.
14. Ram P, Jha, Automatic generation control of interconnected hydro-thermal system in deregulated environment considering generation rate constraints. 2010 Int Conf Ind Electron Control Robot. IECR; 2010. p. 148–59.
15. Saini JS, Jain V. A Genetic Algorithm optimised Fuzzy Logic Controller for automatic generation control for single area system. J Inst Eng Ser B; 2015.

Table 5. Sensitivity analysis with parametric variations

| System Parameters | % Change | \( \Delta f1 \) | \( \Delta f2 \) | \( \Delta P_{tie} \) |
|-------------------|----------|---------------|---------------|-----------------|
|                   |          | \( U_{sh} (x10^{-3}) \) | \( O_{sh} (x10^{-5}) \) | \( T_s \) | \( U_{sh} (x10^{-3}) \) | \( O_{sh} (x10^{-5}) \) | \( T_s \) | \( U_{sh} (x10^{-3}) \) | \( O_{sh} (x10^{-5}) \) | \( T_s \) |
| \( T_g,T_r,T_i,T_p \) | -50%     | -11.54        | 22.76         | 0.93            | -0.88          | 0             | 0             | -0.953          | 0             | 0             |
|                   | -25%     | -21.84        | 3.8           | 3.51            | -3.65          | 0             | 0             | -2.93           | 0             | 0             |
|                   | +25%     | -48.51        | 24.57         | 5.2             | -12.97         | 0.12          | 0.42          | -6.64           | 0             | 6.6           |
|                   | +50%     | -64.2         | 36.88         | 6.53            | -20.78         | 3.29          | 0.37          | -8.38           | 0             | 9.56          |

\( \Delta P_{d1} \) = 0.04.
16. Zolfagharifar SA, Karamizadeh F. Developing a hybrid intelligent classifier by using evolutionary learning (Genetic Algorithm and Decision Tree). Indian Journal of Science and Technology. 2016 May; 9(20):1–8.

17. Mahwish B, Shah TM, Tariq S. Text embedded into encrypted image based on Genetic Algorithm on piece-wise linear chaotic map. Indian Journal of Science and Technology. 2016 Feb; 9(8):1–7.

18. Noersasongo E, Julfia FT, Purwanto AS, Pramunendar RA, Supriyanto C. A tourism arrival forecasting using Genetic Algorithm based neural network. Indian Journal of Science and Technology. 2016 Jan; 9(4):1–5.

19. Kaghed HN, Al–Shamery SN, Khazaal Al-Khuzaie FE. Multiple sequence alignment based on developed Genetic Algorithm. Indian Journal of Science and Technology. 2016 Jan; 9(2):1–7.

20. Najafi S, Dalfard VM, Mohammadi G. Hybrid Genetic Algorithm for network locating problem by considering multi-purpose trip in stochastic state. Indian Journal of Science and Technology. 2011 Sep; 4(9):1–4.

21. Bakken BH, Grande OS. Automatic generation control in a deregulated power system. IEEE Trans Power Syst. 1998; 13(4):1401–6.

22. Christie RD, Bose A. Load frequency control issues in power system operations after deregulation. Proc Power Ind Comput Appl Conf. 1995; 11(3):1191–200.

23. Donde V, Pai MA, Hiskens I. Simulation and optimization in a LFC system after deregulation. IEEE Trans Power Syst. 2001; 16(3):481–9.

24. Debbarma S, Saikia LC, Sinha N. AGC of a multi-area thermal system under deregulated environment using a non-integer controller. Electr Power Syst Res. 2013; 95:175–83.

25. Pati S, Sahu BK, Panda S. Hybrid differential evolution Particle Swarm Optimisation optimised fuzzy proportional–integral derivative controller for automatic generation control of interconnected power system. IET Gener Transm Distrib. 2014; 8(11):1789–800.

26. Sahu R, Panda S, Padhan S. A hybrid firefly algorithm and pattern search technique for automatic generation control of multi area power systems. Int J Electr Power Energy Syst. 2015; 64:9–23.