PROFICIENT CONTROL BASED LOAD FREQUENCY CONTROLLER FOR DEREGULATED HYBRID POWER SYSTEMS WITH SENSITIVITY ANALYSIS

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Abstract: *This paper proposes a sensitivity analysis on the load frequency control (LFC) of two area interconnected systems under the deregulated environment. A linearized hydro and diesel model along with the conventional thermal reheat model is considered for the study. The recent trend of deregulated electricity market involving poolco and bilateral contracts has been incorporated in the system through the realization of Disco Participation Matrix. A suitable fuzzy logic control strategy is formulated to derive the optimal gain setting of the controller using Integral Square Error (ISE) technique. The sensitivity analysis is carried out with the proposed controller following a step load disturbance under the deregulated environment. The proposed control scheme is compared against the conventional controllers under the occurrence of sudden load changes in any of the areas. The simulation results reveals that the dynamic response of the system with fuzzy logic control in the LFC problem provides a better performance against the conventional Proportional plus Integral (PI) controllers. The proposed control technique also suppresses the system frequency and tie-line power oscillations effectively*

Key words: *LFC, DPM, sensitivity analysis, fuzzy logic control, interconnected power systems, deregulation.*

1. Introduction.

The objective of power system and Load Frequency Control is to satisfy the balance between the real power generation & demand and at the same time the desired frequency is ensured along with the tie-line power exchange with neighboring system is to be maintained within the scheduled limits. With deregulation there is also a stringent limit being imposed on frequency variations as there is a need to make sure electricity reaches the consumers with good quality and reliability. To ensure reliability adequate generation is necessary. At the same time, global warming surges to influence the atmosphere in terms of an escalated rise in the temperature. Hence the present trend ventures to incorporate the smart grid energy systems in combination with other non-polluting energy resources leading to hybrid power generation. In this paper hydro-diesel power plant combined with thermal power plants operated in an interconnected system under the deregulated environment is taken for study. A decentralized load frequency controller is designed for an interconnected hydro-thermal system under deregulated environment with conventional controller tuning was presented [10- 12]. Proportional integral controller (PID) designed for gas-thermal power system reduced the steady state error significantly. The importance of sensitivity analysis is dealt and the controller design has been presented [14-16]. However while dealing with deregulated systems, an intelligent controller becomes highly essential in order to achieve better desired performance of the system. Hence a fuzzy controller is suggested. It has been adopted by some researchers in LFC problem. The idea of designing a fuzzy controller for the LFC problem on the proposed hybrid interconnected system is a novel scheme and it is being realized in their study. As the smart grid power system involves interconnection of other sources with conventional sources, the energy supply can be increased. However, with increasing load demand, the system frequency becomes under check. Therefore to realize the dynamics in the load, sensitivity analysis is carried out on the load damping co efficient as it gains significant importance. Loading characteristics is changed by varying the damping co efficient in step by step manner for 20%, 40%, 60%, 80% and 100%.

2. System design

The proposed system consists of the hydro, diesel energy generation that is interconnected with a conventional reheat thermal system[1]. A linearized model of hydro, diesel and thermal power systems presented in [10-12] have been adopted. The electricity market rules in the deregulation environment are imposed in the proposed system through the disco participation matrix (DPM). The DPM is formulated accordingly to the contracts between the distributions companies (DISCOs) and generation companies (GENCOs) [2]. In this proposed model, Area-1 comprising two thermal units and area-2 comprising two units out of which one unit of diesel and another one unit of hydro systems. Both areas constructed in

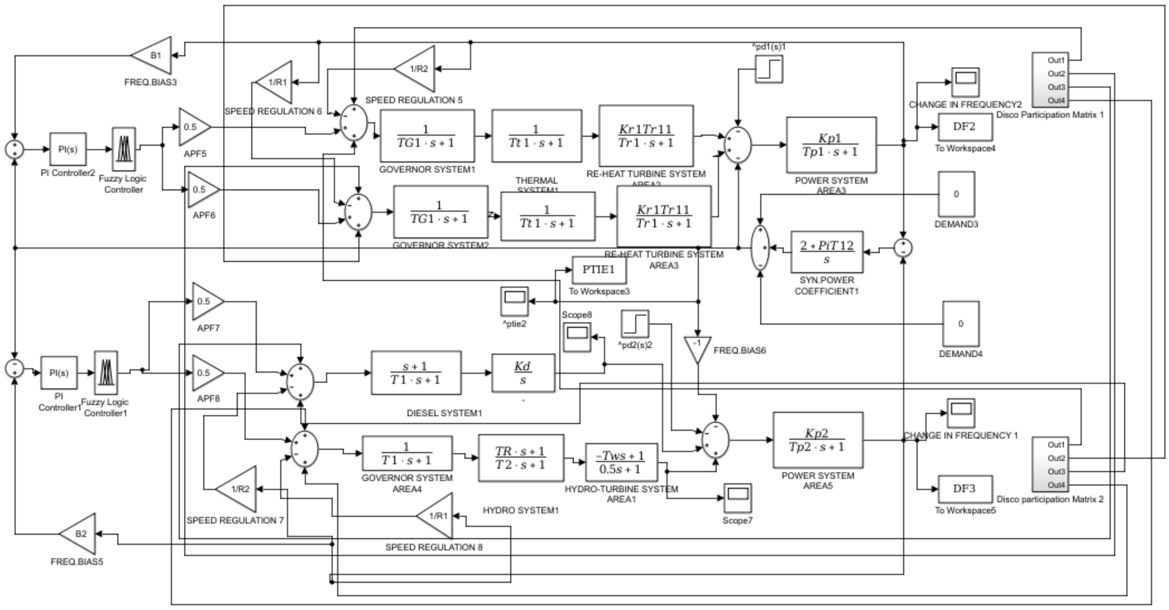

Fig.1. Transfer function model of hydro-thermal- diesel power systems

LFC schemes under the deregulated environment. The projected transfer function model of hydro thermal diesel power system as shown in fig.1. A conventional PI controller has been formulated and tuned based on Integral Square Error (ISE) criterion when the system considered is provided with a small disturbance.

3. Design of controllers

3.1 Conventional controller:

In automation Industries, the PI controller design is the supreme acquainted operation because of robustness, easy to comprehend and obtain virtuous operation in dynamic performance. The function of Proportional (P) and Integral (I) controller has been reducing the consequence of rise time and the effect of eliminating the balanced error and enhancing the stability of the system respectively. For area-1 and area-2, the controller output is represented as IP^1 and IP^2 which is control inputs to the aforesaid output function. For PI controller,

$$IP^1 = K_{p1}\, e_1(t) + K_{I1} \int e_1(t)\, dt \qquad .....(1)$$

$$IP^2 = K_{p2}\, e_2(t) + K_{I2} \int e_2(t)\, dt \qquad .....(2)$$

The optimized gain value of K_p and K_i are preferred based on performance index curve. The objective function is formulated by means of Integral Square Error (ISE) criterion, which is defined as,

$$J = \int_o^t (\delta Ptie_{1-2}^2 + \delta f_1^2 + \delta f_2^2)\, dt \qquad ......(3)$$

where, $\delta\, Ptie_{(1-2)}$ is change in tie-line power, δf_1 *and* δf_2 are steady state change in frequency for area 1 and area 2 respectively and *dt* is small time interval during the sample. The optimized gain values (K_p and K_i) are assimilated from the performance index curve method. The achieved gain values are once fixed in the conventional controller. However in the deregulation problems, the conventional controller may not be sufficient to satisfy the operation. In addition, the limitations of conventional controllers are sluggish and lack of effectiveness in handling with system non linearity. Therefore, to overcome the aforementioned drawbacks the application of intelligent controller approach is essential for the complex problems.

3.2 Fuzzy logic controller:

Fuzzy logic approach is realizing unique performance over the conventional one, FLC is cheaper comparatively other controllers in terms of performance, more robust than PI controller because of their huge range of operating conditions, customizable, more reliable and it provides more efficiency rather than conventional controller, in accumulation, it is observed that the FLC reduce the overshoot or undershoot, faster settling, attractive for dealing with complex problems [6, 7, 8]. Following are the major components in fuzzy logic controller; they are fuzzifier, fuzzy knowledge base, fuzzy rule base, inference engine and defuzzifier. For designing, the numeric values are replaced by linguistic variable which is called fuzzifier. The power system variables and area control error (ACE) and all inputs are chosen from PI fuzzy controller. The membership function is shown in the fig.2 & 3 for each input and output the different membership function is framed and the magnitude of the membership is presented in fig.4. As the number of membership function is increased, the desired response and the computation time also increased [13].

3.2.1 Rule base
In this design, there are two inputs and five membership functions(S=0;M=1;B=2;VB=3;VVB=4) are derived, therefore totally 25 rules are manipulated which is displayed in table-2 for example: input-1 (ACE of area-1) is NB and input-2(ACE of area-2) is NB then output (frequency) is S.

4. Case study

There are two cases are discussed in the proposed system, they are,
Case-1: Poolco contracts through DPM:
Case-2: bilateral transactions:
The brief discussion of above mentioned cases as follows,
Case-1: Poolco contracts through DPM:
The GENCOs in each area participate equally in LFC; i.e., ACE participation factors are apf1= 0.5, apf2=1-apf1=0.5; apf3=0.5, apf4=1-apf3=0.5. The load change occurs only in area-1. Thus, the load is demanded only by DISCO1 and DISCO2. Let the value of this load demand be 0.1 p.u. MW for each of them. Therefore Disco Participation Matrix [2] becomes,

$$DPM= \begin{pmatrix} 0.50 & 0.50 & 0 & 0 \\ 0.50 & 0.50 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}$$

Genco's scheduled powers will be,

GENCO1 (scheduled)
$= (0.5+0.5+0.0+0.0) \times 0.1 = 0.55\ p.u$ .....(4)
GENCO2 (scheduled)
$= (0.5+0.5+0.0+0.0) \times 0.1 = 0.55\ p.u$ .....(5)
GENCO3 (scheduled)
$= (0.0+0.0+0.0+0.0) \times 0.1 = 0.0\ p.u$ .....(6)
GENCO4 (scheduled)
$= (0.0+0.0+0.0+0.0) \times 0.1 = 0.0\ p.u$ .....(7)

From the equation (6) and (7), it is observed that the participation factors are zero. Because DISCO3 and DISCO4 are unable to meet out the demand power from any GENCOs, therefore the corresponding DISCO1 and DISCO2 demand identically for their local GENCOs.

The objective function of GENCO's is given below,

$$\Sigma\ (pu\_MW\_load\_of\_DISCO\_'d')*cpf1,d = 0.1p.u \quad .....(8)$$

case-2: bilateral transactions:
Consider a case where all the DISCOs contract with the GENCOs for power as per the following DISCO Participation Matrix (DPM):

$$DPM = \begin{pmatrix} 0.5 & 0.25 & 0 & 0.3 \\ 0.2 & 0.25 & 0 & 0 \\ 0 & 0.25 & 1 & 0.7 \\ 0.3 & 0.25 & 0 & 0 \end{pmatrix}$$

Therefore,
GENCO1 (scheduled)
$= (0.5+0.25+0.0+0.3) \times 0.1 = 0.105\ p.u.$ ..... (9)
GENCO2 (scheduled)
$= (0.2+0.25+0.0+0.0) \times 0.1 = 0.045\ p.u$ ..... (10)
GENCO3 (scheduled)
$= (0.0+0.25+1+0.7) \times 0.1 = 0.195\ p.u$ .....(11)
GENCO4 (scheduled)
$= (0.3+0.25+0.0+0.0) \times 0.1 = 0.055\ p.u$ .....(12)

It is assumed that each DISCO demands 0.1 p.u. MW power from GENCOs as defined by cpfs (contract participation factors) in DPM matrix. The off diagonal blocks of the DPM correspond to the contract of a DISCO in one area with a GENCO in another area. Both the case studies formulated and tabulated results shown in table-1 and the scheduled powers depicted in fig. (11-14).

***5.* Results and discussions**

The model is simulated in the MATLAB Simulink environment for a step load disturbance in the area -1. The results reveal that after the given load disturbance, the system frequency oscillates and settles to a final steady state value because of the controller action. Also the fig.5 shows that the system possess better performance in terms of minimum overshoot and faster settling time with the fuzzy PI controller. Similarly the frequency response (fig.6) in the area-2 is superior with the fuzzy PI controller. The tie line power exchange also shows better dynamic characteristics with the fuzzy PI shown in fig.7. Thus in all aspects the simulation results describe that the designed fuzzy PI controller proves to be better than the conventional PI controller.

Table-1 Gencos Scheduled Power for Poolco and Bilateral Contracts

Area	***Genco's Scheduled power in p.u MW***	***Case-1***	***Case-2***
Area-1	*Genco-1*	*0.55*	*0.105*
	Genco-2	*0.55*	*0.045*
Area-2	*Genco-3*	*0*	*0.195*
	Genco-4	*0*	*0.055*

Table-2 Fuzzy Rules

Area2 & Area1	*NB*	*NS*	*ZZ*	*PS*	*PB*
NB	*0*	*0*	*1*	*1*	*2*
NS	*0*	*1*	*1*	*2*	*3*
ZZ	*1*	*1*	*2*	*3*	*3*
PS	*1*	*2*	*3*	*3*	*4*
PB	*2*	*3*	*3*	*4*	*4*

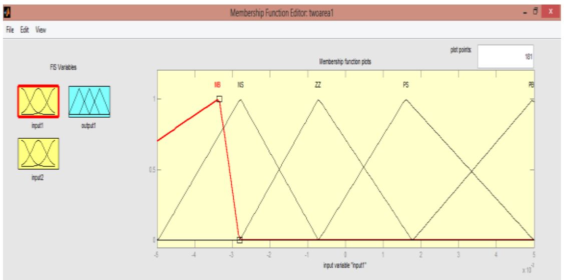

Fig. 2 Fuzzy interface system input-1(area-1)

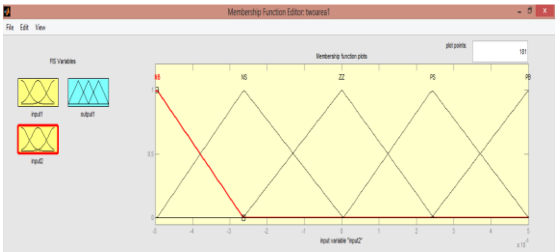

Fig. 3 Fuzzy interface system input-2(area-2)

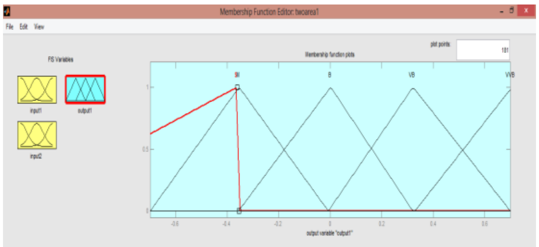

Fig. 4 Fuzzy interface system output

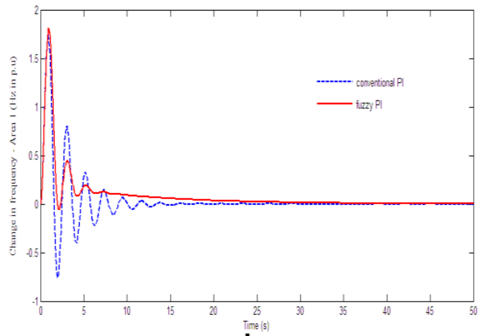

Fig.5 Comparison of change in Frequency response characteristics of area-1

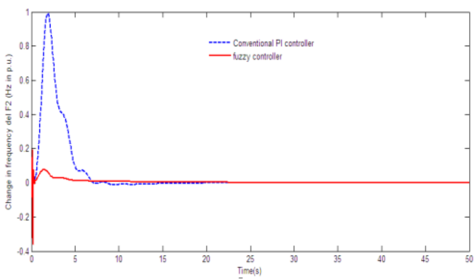

Fig.6 Comparison of change in Frequency response characteristics of area-2

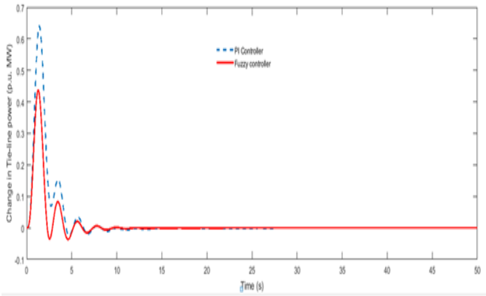

Fig.7. Comparison of Tie-line power. Area-1 & 2

The fig. 8,9,10. depicits the sentivity anlaysis that is being performed on the system. It clearly shows that that the dynamic characterisitcs are shifted appropiately for various loading characteristics.

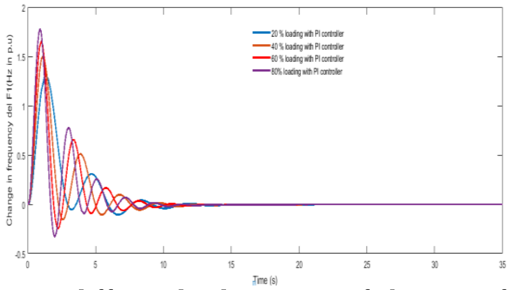

Fig.8.different load variation of change in frequency response characteristics of Area-1

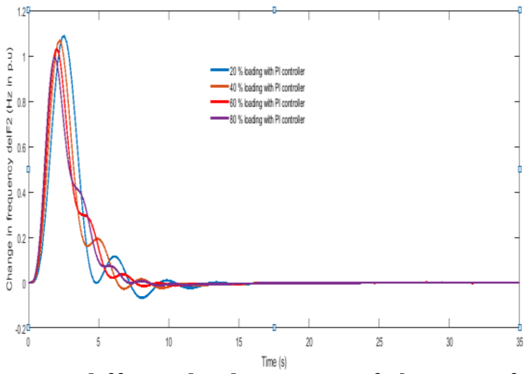

Fig.9. different load variation of change in frequency response characteristics of Area-2

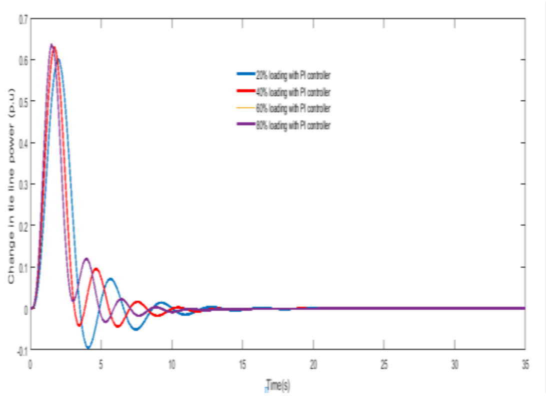

Fig.10. different load variation of tie-line power in Area-1 &2

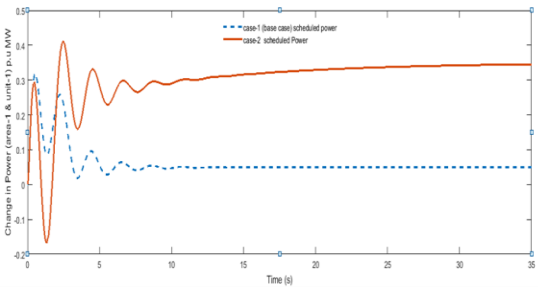

Fig.11.Scheduled power in area-1(Genco-1) for case-1 & 2

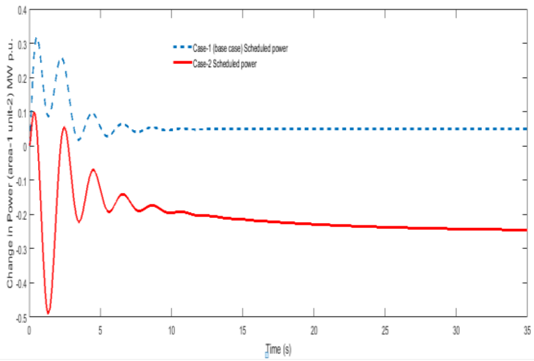

Fig.12. .Scheduled power in area-1(Genco-2) for case-1 & 2

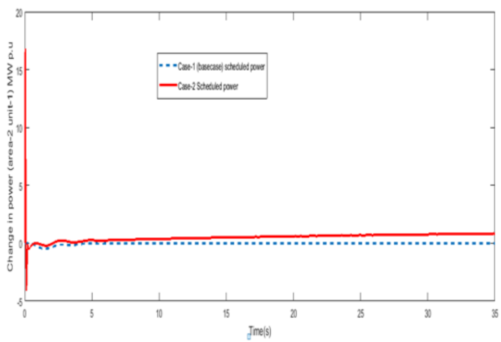

Fig.13. Scheduled power in area-(Genco-3) for case-1 & 2

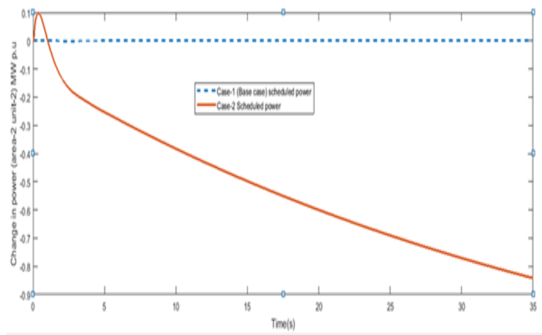

Fig.14.Scheduled power in area-2 (Genco-4) for case 1&2

6. Conclusion

The idea of intelligent controller for hybrid interconnected system under the deregulated environment was proposed and the same was implemented successfully through the design of a fuzzy controller. Better results were also yielded with the proposed controller on the investigated system. This idea of intelligent controllers can be extended for the sensitivity analysis approach and can be implemented on the systems with renewable energy penetrations that includes solar, wind, fuel cells and also to the systems with storage or FACTS devices. The variation of system parameters along with the varaitions of loading characteristics in the renewable energy systems will be a significant extension of this work.

References

1. P. Kundur, *Power System Stability and Control*. New York: McGraw- Hill, 1994.

2. V. Donde, M. A. Pai and I. A. Hiskens, *"Simulation and Optimization in an AGC System after Deregulation"*, IEEE Transactions on Power Systems, Vol. 16, No.3, August 2001, pp 481-488.

3. Tripathy SC, balasubramaniyan R, chanramohanan Nair PS, *''Effect of superconducting magnetic energy storage on Automatic Generation control considering governor dead band and boiler dynamics''* IEEE Transaction on power systems 1992:3(7):1266-73.

4. Richard D. Christie, Anjan Bose, *"Load Frequency Control Issues in Power System Operations after Deregulation"*, IEEE Transactions on Power Systems, V01.11, No.3,August 1996, pp 1191-1196.

5. J. Kumar, Kah-Hoe Ng and G. Sheble, *"AGC Simulator for Price- Based Operation: Part II*", IEEE Transactions on Power Systems,Vol.12, No.2, May 1997, pp 533-538.
6. A.Demiroren, and E.Yesil*,"Automatic Generation Control with Fuzzy Logic Controllers in the Power System Including SMES Units",* Electrical Power and Energy Systems, 26 (2004) 291-305.
7. Kazuto Yukita, Yasuyuki Goto, Katsunori Mizuno, Toshihiro Miyafuji and Katsuhiro Ichiyanagi, *" Study of Load Frequency Control using Fuzzy Theory by Combined Cycle Power Plant"*, 2000 IEEE 0-7803- 6/00, pp. 422-427.
8. Xiangjie Liu and Tianyou Chai, *"A Weighted Algorithm of Fuzzy Logic Strategy on Water Level Control of Steam Generator",*Proceedings of the 36th Conference on Decision & Control, San Diego, USA,Dec. 1997, pp. 3357-3362.
9. I.A.Chidambaram and S.Velusami, *''Decentralized Biased Controllers for Load-frequency control of interconnected power systems considering Governor Dead Band Non-linearity''* IEEE INDICON 2005 Conference;521-525.
10. M.VinothKumar, Dr.C.Kumar *"Simulation of decentralized load-frequency controller for deregulated gas- thermal power systems - A case study"* International Journal of Applied Engineering Research, ISSN 0973-4562 Vol. 10 No.51 (2015),pp285-291.
11. D.Dasa, S.K.Aditya, D.P.Kothari, Dynamics of diesel and wind turbine generators on an isolated power system,Electr. Power Energy syst.21(1999) 183-189.
12. Elgerd. O. I., *"Energy Systems Theory: an introduction",* New York: McGraw-Hill, 1982.Electric.
13. www.mathworks.com
14. L. Yao and H. Lu, *"A two-way direct control of central air-conditioning load via the internet,"* IEEE Trans. Power Del., vol. 24, no. 1, pp. 240–248, Jan. 2009.
15. Umesh kumar rout, Rabindra Kumar sahu, sidhartha panda, *"design and analysis of differential evolution algorithm based automatic generation control for interconnected power system"* Ain shams Engineering journal (2013)4,409-421

16. N. Ruiz, I. Cobelo, and J. Oyarzabal, "A direct load control model for virtual power plant management," IEEE Trans. Power Syst., vol. 24, no. 2, pp. 959–966, May 2009.

APPENDIX

a)System Data (thermal system):

Kp_1=kp_2=120 Hz/p.u. MW T_2=0.513s
Tp_1=Tp_2=20s Tg=0.08s
R_1=R_2=2.4 hz/p.u. MW Tr=5s
B_1=B_2=0.4249
D1=D2=$8.33*10^{-3}$ pu MW/Hz
Pr_1=Pr_2=1200MW, T_{12}=0.0866, T_1=41.6s.

b) Hydro

T12=0.0866
T1=41.6s
T2=0.513s
Tr=5s
Tw=1s

c) Diesel power system:

Kd=16.5 p.u Kw/Hz
Tp1=0.60 s
Tp2=0.041 s
Kpc=0.80ctively
Tk=0.0009 s