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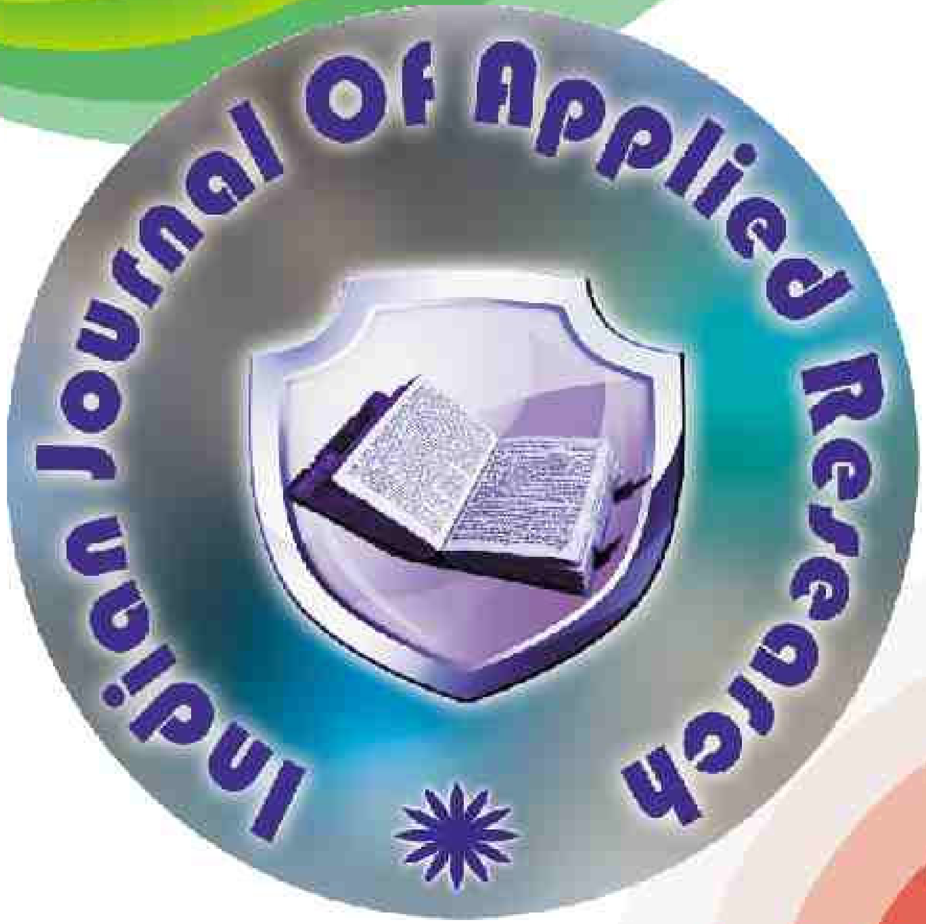

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Research Paper Engineering

Design Of Decentralized Load-Frequency Controller For Deregulated Hydro-Thermal Power Systems With Non-Linearities

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ABSTRACT

This paper presents a design of decentralized load frequency controllers for deregulated hydro-thermal power systems with non-linearities is proposed for the load frequency control (LFC) problem in a deregulated power systems. Load frequency control is very important issue in power system operation and control for supply sufficient and reliable electric power with good quality. LFC is treated as an ancillary service, which is essential for maintaining the electrical system reliability at an adequate level. The system is incorporated with Governor dead band and Generation rate constraints non-linearities. The conventional PI controllers are used to obtain the optimum value to restore the frequency and tie-line power in very smooth way to its nominal value in the shortest possible time. The optimal controller gains are KP and KI to be obtained for the system considered.

The simulation result shows the frequency response of the system with Governor dead band (GDB) and Generation rate constraints (GRC) non-linearities under the two area interconnected hydro-thermal power Systems. Studies reveal the satisfactory operation of the hydro-thermal system conforming to the requirements in the deregulated power systems.

Keywords : Load- frequency control, DISCO, Participation Matrix, GDB, GRC Non-linearities.

Introduction

The dynamic behavior of many power systems are resulted in industrial loads heavily depends on disturbances and particular changes in the operating point. Load-frequency control (LFC) in power systems is very important in order to supply reliable electric power with good quality. The goal of the LFC is to maintain stable system frequency with zero steady state errors and to maintain the tie-line power flow within the specified limits. Power systems are divided into control areas connected with tie-lines. All generators are supposed to constitute a coherent group in each control area. Each area needs the system frequency to be controlled. Electric power systems operating in an interconnected grid are normally composed of control areas or regions and interconnected through tie-lines. The important tasks of LFC is covering the customers load requirements as well as maintaining the interchanged power and the system frequency at their respective scheduled values so that the power system remains at its nominal state characterized by nominal system frequency , voltage profile and load flow configuration. To maintain the power system in its nominal state, at each instant, the generated power should be exactly match the demanded power plus the associated system losses. But in a practical power system, the load is changing continuously. Further, the ability of the generation to track the changing load is limited due to physical/technical considerations. Thus the ability of the LFC concerned this try to overcome this problem and instantaneously matching the generation to the system load and adjusting the system frequency and tie-line loadings at their scheduled values as close as possible so that, the quality of the power delivered is maintained at the requisite level. The Governor Dead Band (GDB) effects are neglected in the Load-Frequency Control studies for simplicity. But for the realistic analysis of system performance, these should be incorporated as they have considerable effects on amplitude and settling time of oscillations [3], [4], [5]. Generally, ordinary LFC systems are designed with Proportional-Integral (P-I) controllers. However, since the integral parameters are usually tuned, it is incapable of obtaining good dynamic performance for various load and system change scenarios. In the last one and half decade, the concept of deregulation has been introduced to power system. The role of the deregulation of the electricity market is as follows: 1.unbundling: separating vertically integrated utility into three different independent entities, i.e. GENCOs, TRANSCOs and DISCOs. 2. Annulling of exclusive rights: no exclusive territories for any company any more. 3. Third party access: all customers should get access to the transmission or supply grid.

Literature Survey And Data Collection

Many authors have made attempts to describe modified AGC for deregulated power system. Literature survey shows that most of the earlier work in the area of automatic generation control in deregulated power system pertains to interconnected thermal system and no attention has been devoted to hydro-thermal systems involving thermal and hydro subsystems of widely different characteristics. Donde, Pai and Hiskens [1] present AGC of a two area non-reheat thermal system in deregulated power system.

The concept of DISCO participation matrix (DPM) and area participation factor (APF) to represent bilateral contracts are introduced The dynamic behavior of the frequency of each area and tie-line power deviation in the power system considering non-linearities has been outlined [3]. Integral Square Error (ISE) technique has been used to conventional PI-controller gains. The governor dead band (GDB) effects are neglected in the Load-Frequency Control studies for simplicity. But for the realistic analysis of system performance, these should be incorporated. [3,4].Christie and Bose [5] have dealt with LFC (Load Frequency Control) issues in deregulated power system. The paper discusses the possible structures such as' Free', 'Charged' and 'Bilateral' LFCs for providing real power control in deregulated environment. The review of literature in the context of LFC in the deregulated environment shows that no work has been reported for deregulated hydro-thermal systems with non-linearities. Under the new paradigm, automatic generation control operation is accountable to load following contracts. It will also meet the control performance criteria as long as the area control error (ACE) is a part of the control objective.

The sensitivity of the optimal controller gains to DPM & APF has also been brought out. The selection of suitable values brought out for governor speed regulation parameter R for the hydro and thermal plants in the deregulated mode. System reveals the satisfactory operation of the hydro-thermal system conforming to the requirement in the deregulated power system.

System Investigated

The system investigated consists of two generating areas of equal size. Area I comprises a reheat thermal-hydro system with two GENCOs of equal capacity and Area 2 comprising another reheat thermal-hydro system with two GENCOs. Figure 1 shows the new transfer function LFC model with single stage reheat turbine in thermal area and governor in hydro area are considered for deregulated environment. Area I has two DISCOs and Area 2 has two DISCOs. A bias setting of Bi = βi is considered for both hydro and thermal areas. The system model is considered for continuous mode operation. The nominal system parameters are given in the appendix. The optimum values of proportional and integral gains for the governor and optimum gain for the integral controllers have been selected using ISE (Integral Square Error) criterion. The cost function J for ISE is taken as

$$J=\int (\Delta P^2_{tie\,(1-2)} + \Delta F^2_{\ 1} + \Delta F^2_{\ 2})\, dt$$

Where,

dt = small time interval during sample,

$P_{tie\,(1-2)}$ = incremental change in tie-line power,

f_1,f_2 = incremental change in frequency area 1 & area2 respectively.

System Formulation

In this section, we formulate the block diagram for a two-area LFC system in the deregulated scenario. 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 PL1 and PL2 should be reflected in the deregulated LFC 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 LFC. Coefficients that distribute ACE to several

GENCOs are termed as "ACE participation factors" (apfs). Note that $\sum^{m}_{j=1}$ apf $_{j=1}$ where 'm' is the number of GENCOs. Unlike in the traditional LFC system, a DISCO asks/demands a particular GENCO or GENCOs for load power. These demands must be reflected in the dynamics of the system. Turbine and governor units must respond to this power demand. 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 [1]. Here, we introduce the information signals which were absent in the traditional scenario. The demands are specified by cpfs (elements of DPM) and the pu MW 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

$\Delta P_{tie1\text{-}2,scheduled}$ =(demand of DISCOs in area II from GENCOs in area I) - (demand of DISCOs in area I from GENCOs in area II) ----- (1)

At any given time, the tie line power error $\Delta P_{tie1\text{-}2,error}$ is defined as

$$\Delta P_{tie1\text{-}2,error} = \Delta P_{tie1\text{-}2,actual} - \Delta P_{tie1\text{-}2,scheduled} \quad \text{----- (2)}$$

$\Delta P_{tie1\text{-}2,error}$ 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.

$$ACE_1 = B_1 f_1 + \Delta P_{tie1\text{-}2,error}$$
$$ACE_2 = B_2 f_2 + \Delta P_{tie2\text{-}1,error} \quad \text{------(3)}$$

where

$$\Delta P_{tie2\text{-}1,error} = -Pr_1/Pr_2\, \Delta P_{tie1\text{-}2,error} \quad \text{----- (4)}$$

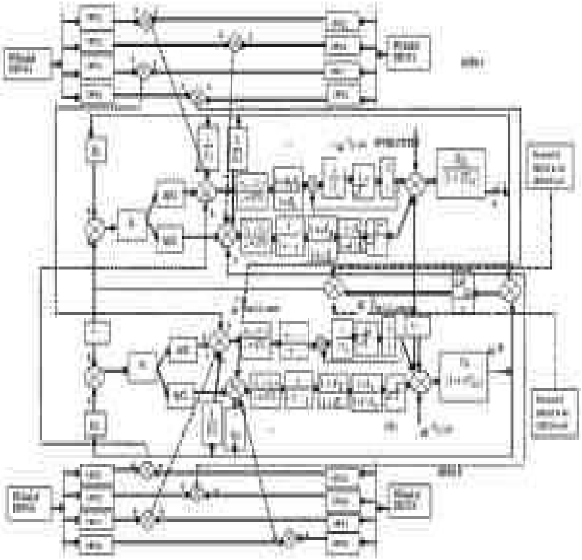
and Pr_1, Pr_2 are the rated powers of areas I and II, respectively. Therefore,

$$ACE_2 = B_2\, \Delta f_2 + \alpha_{12} \Delta P_{tie1\text{-}2,error}$$

Where, $\alpha_{12} = -Pr1/Pr_2$

The block diagram for LFC with deregulated hydro-thermal power systems is shown in Fig.1

Fig.1. Block Diagram of Load-Frequency Controller for Deregulated Hydro-Thermal Power Systems with GDB & GRC Non-Linearities



Physical Constraints In Lfc

Generation Rate Constraint (GRC):

An important physical constraint is the rate of change of power generation due to the limitation of thermal and mechanical movements. LFC studies that do not take into account the delays caused by the crossover elements in a thermal unit, or the behaviour of the penstocks in a hydraulic installation, in addition to the sampling interval of the data acquisition system, results in a situation where frequency and tie-line power could be returned to their scheduled value within 1 s.

In a real LFC system, rapidly varying components of system signals are almost unobservable due to various filters involved in the process. Hence, the performance of a designed LFC system is dependent on how generation units respond to the control signal. A very fast response for an LFC system is neither possible nor desirable [10]. A useful control strategy must be able to maintain sufficient levels of reserved control range and control rate.

In practice, there exit a minimum and maximum limit on the rate of change in the generating power (PG). Figure.2 shows the generation rate Constraint (GRC). Due to adiabatic expansion, sudden power decrease would draw out excessive steam from boiler system to cause steam condensation. The steam value of high pressure turbine acts as a control valve associated with LFC. The boiler can afford to keep its steam pressure to be constant for a while and thus, it is possible to increase generation power of to certain limit of normal power during the first few seconds. After the generation has reached this upper bound the power increases of the turbine should be restricted by GRC (kundur., 1994).

The literature has shown that the dynamic responses of the system with the presence of GRC have larger overshoots and longer settling times, compared to system without GRC. Furthermore, if the parameters of the controller are not chosen properly, the system may become unstable. The generation rate constraint of 0.0017 p.u MW /sec is considered here for thermal system,[15,16] ie.,

$$\Delta \dot{P}_g \le 0.1\,\text{p.u.MW min}^{-1} = 0.0017\,\text{p.u.MW sec}^{-1}$$

The typical value of permissible rate of generation for hydro system is much higher than thermal system. In this present study, GRC of 4.5 % per sec for rising generation and 6 % per sec for lowering generation is considered.

Fig.2. Generation Rate Constraint

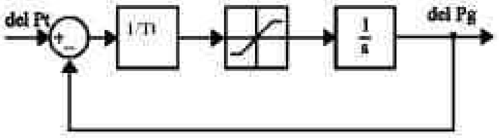
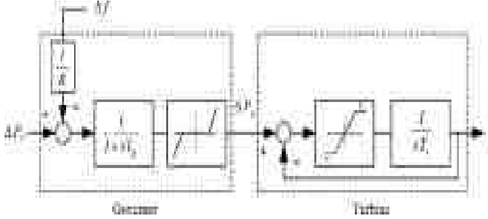


Fig.3. Generator unit model with GRC and dead band



Governor Dead Band (GDB):

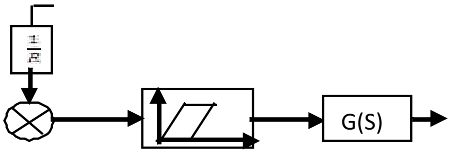
Speed governor dead band is known as another important issue in power system performance. By changing the input signal, the speed governor may not immediately react until the input reaches a specified value. All governors have a dead band in response, which is important for power system frequency control in the presence of disturbances.

Governor Dead Band (GDB) is defined as the total magnitude of a sustained speed change within which there is no resulting change in valve position. The backlash non-linearity tends to produce a continuous sinusoidal oscillation with a natural period of about 2s (Tripathy et al., 1992) the speed governor dead band has significant effect on the dynamic performance of load frequency control mechanism. In this study, describing function approach is used to incorporate the governor dead band non-linearity. The hysteresis types of non-linearities are expresses as:

$y = F(x, \dot{x})$ rather than as $y = F(x)$ ……… (5)

To solve the non-linear problem, it is necessary to make the basic assumption that the variable x, appearing in the Eq. 5 is sufficiently close to a sinusoidal Eq.6 that is:

Fig. 4. Nonlinear Turbine Model with GDB



$X \approx A\,Sin\,t\omega_0 t$ …… (6)

Where

A is amplitude of oscillation

ω_0 is frequency of oscillations

$\omega_0 = 2\pi f_0 = \pi$; with f_0 = 0.5 Hz ….. (7) .

As the variable function is complex and periodic function of time, it can be developed in a Fourier series as (Tripathy et al., 1992):

$$F(x, \dot{x}) = F^0 + N_1 x + \frac{N_2}{\omega_0}\dot{x} + \ldots \qquad \text{………} (8)$$

As the backlash nonlinearity is symmetrical about the origin, *F*0 is zero. For the analysis, in this study, backlash non-linearity of about 0.05% [2] for thermal system is considered. From eq. (5) simplification, neglect higher order terms, the Fourier co-efficient are derived as N_1=0.8 & N_2=-0.2. By substituting the N_1 and N_2 values in equation (8) the transfer function model of Governor Dead Band non-linearity is expressed as:

$$F(x, \dot{x}) = 0.8x - \frac{0.2}{\pi}\dot{x} \qquad \text{…………} (9)$$

For hydro system, the dead band non-linearity is about 0.02% is considered, in this study.[9, 10]

Case Study

Case -1: Base Case

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 I. Thus, the load is demanded only by DISCO1 and DISCO2. Let the value of this load perturbation be 0.1 pu MW for each of them. Therefore DPM becomes,

$$\text{DPM} = \begin{bmatrix} 0.5 & 0.5 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

The DISCO3 and DISCO4 do not demand power from any GENCOs, and hence the corresponding participation factors (columns 3 and 4) are zero. DISCO1 and DISCO2 demand identically from their local GENCOs, viz., GENCO1 and GENCO2. The frequency deviations in area I to area II, actual tie-line power flow in a direction from area 1 to area2 and the generated powers of various GENCOs, following a step change in loads of DISCO1 and DISCO2.The tie line power goes to zero in the steady state as there are no contracts of the DISCO's in other areas. In the steady state, the generation of each GENCO matches the demand of the DISCOs in contract with it. Eg.GENCO1 generates

$\sum$ (pu_MW_load_of_DISCO_'d')*cpf1,d = 0.1p.u

As GENCO3 and GENCO4 are not contracted by any DISCOs their generation change is zero in the steady state.

Optimization of Integral Controller Gains:

The optimum values of integral controllers are found on the basis of minimum cost function (J). The sets of optimum gains are obtained for different type of systems using ISE criterion and are presented in table1.

Table.1 Conventional PI-Controller gain values

Type of gain	**GDB**	**GRC**	**GDB & GRC**
Optimum Gain Value for K_p	0.3	1.4	0.8
Optimum Gain Value for K_i	0.09	0.2	0.06

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):

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

It is assumed that each DISCO demands 0.1 pu MW power from GENCOs as defined by cpfs 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.

Effect Of Dpm

In deregulated environment, the DISCO participation matrix (DPM) is chosen on the basis of open market strategy. As the market economy is changing everyday therefore the DPM matrix will not remain the same all the time. Change of DPM changes the generation schedule of all the GENCOs and hence the system behaviour in the restructured environment. So it is interesting to know how the system behaves in the deregulated environment with change in the DPM matrix. To examine this, Different distribution participation matrices (DPM) are introduced on the basis of performance index and optimum values of integral gains and governor parameters are obtained for each case using ISE criterion.

Simulation Results And Observations

The simulation results shows that the frequency response of the system with Governor dead band (GDB) and Generation rate constraints (GRC) non-linearities under the two area interconnected hydro-thermal power Systems. The case studies reveal the satisfactory operation of the hydro-thermal system conforming to the requirements in the deregulated power systems with non-linearities.

In this paper tried two cases in bilateral transactions. For the first case in fig. 5, 6 &7 shows the frequency deviation (ΔF_1) in area I & frequency deviation (ΔF_2) in area II and Tie-line power deviation (ΔP_{tie}) in deregulated hydro-thermal power systems with GDB non-linearity. Fig. 8, 9 & 10 shows the frequency deviation (ΔF_1) in area I, frequency deviation (ΔF_2) in area II and Tie-line power deviation (ΔP_{tie}) in deregulated hydro-thermal power systems with GRC non-linearity respectively. In fig.11, 12 & 13 shows the frequency deviation (ΔF_1) in area I & frequency deviation (ΔF_2) in area II and Tie-line power deviation (ΔP_{tie}) in deregulated hydro-thermal power systems with GDB-GRC non-linearities. For the second case in fig. 14, 15,16,17,18 & 19 shows the frequency deviation (ΔF_1) in area I, frequency deviation (ΔF_2) in area II and Tie-line power deviation (ΔP_{tie}) in deregulated hydro-thermal power systems with non-linearities correspondingly.

Fig.5. Frequency deviation in area 1 in a deregulated hydro-thermal Power Systems with GDB Non-linearity for case-1

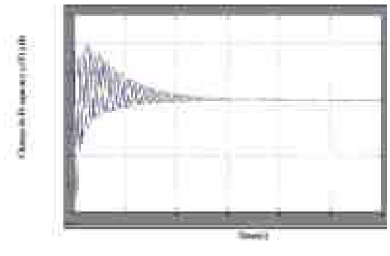


Fig.6. Frequency deviation in area I1 in a Deregulated hydro-thermal Power Systems with GDB Non-linearity for case-1

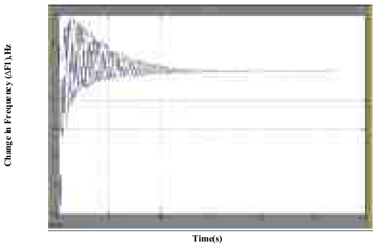


Fig.7. Tie-Line Power deviation in a Deregulated hydro-thermal Power Systems with GDB Non-linearity for case-1

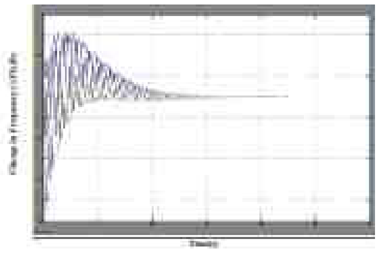


Fig.8. Frequency deviation in area 1 in a Deregulated hydro-thermal Power Systems with GRC Non-linearity for case-

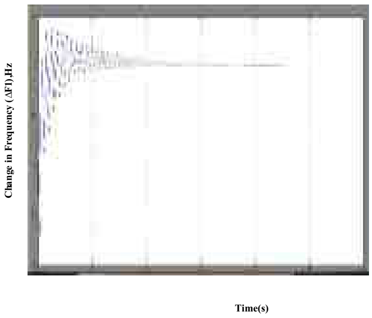


Fig.9. Frequency deviation in area II in a Deregulated hydro-thermal Power Systems with GRC Non-linearity for case-1

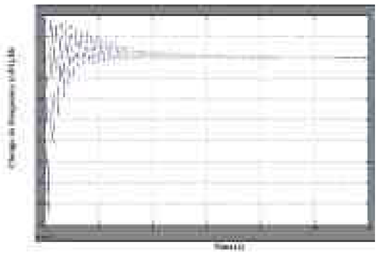


Fig.10. Tie-Line Power deviation in a Deregulated hydro-thermal Power Systems with GRC Non-linearity for case-1

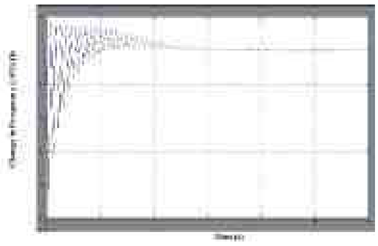


Fig.11. Frequency deviation in area I in a Deregulated hydro-thermal Power Systems with GDB-GRC Non-linearities for case-1

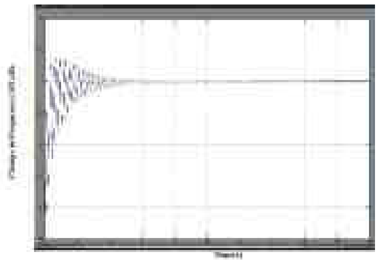


Fig.12. Frequency deviation in area II in Deregulated hydro-thermal Power SystemsWith GDB-GRC Non-linearities for case-1

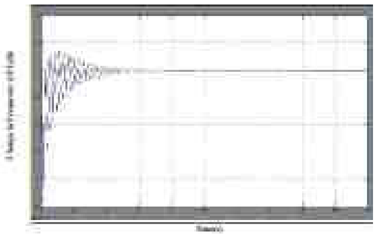


Fig.13. Tie-Line Power deviation in a Deregulated hydro-thermal Power Systems with GDB-GRC Non-linearities for case-1

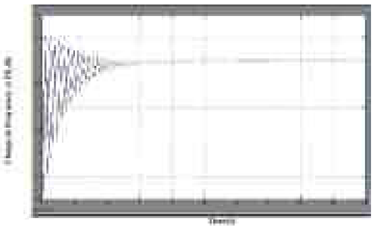


Fig.14. Frequency deviation in area 1 in a Deregulated hydro-thermal Power Systems with GDB Non-linearity for case-2

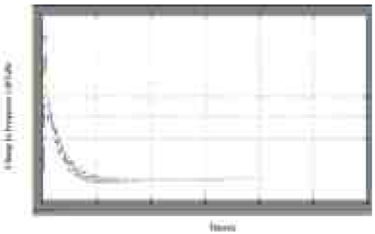


Fig.15. Frequency deviation in area I1 in a Deregulated hydro-thermal Power Systems with GDB Non-linearityfor case-2

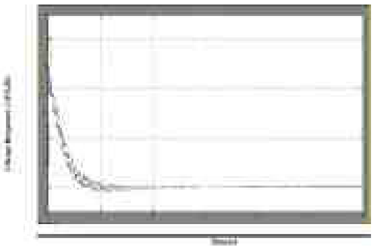


Fig.16. Tie-Line Power deviation in a Deregulated hydro-thermal Power Systems with GDB Non-linearity for case-2

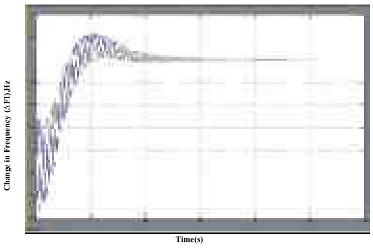


Fig.17. Frequency deviation in area 1 in a Deregulated hydro-thermal Power Systems with GRC Non-linearity for case-2

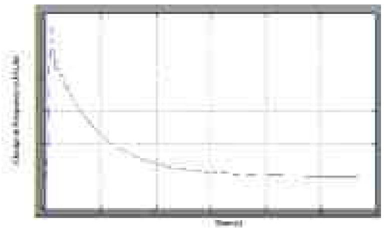


Fig.18. Frequency deviation in area I1 in a Deregulated hydro-thermal Power Systems with GRC Non-linearity for case-2

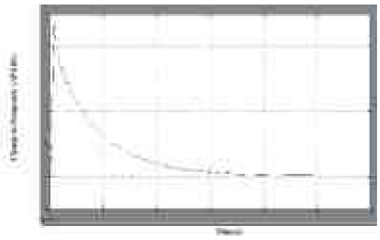
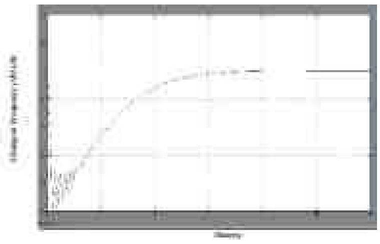


Fig.19. Tie-Line Power deviation in a Deregulated hydro-thermal Power Systems with GRC Non-linearity for case-2



Conclusion

LFC provides a relatively simple, yet extremely effective method of adjusting generation to minimize frequency deviations and regulate Tie-line power flow. Integral square Error (ISE) technique is used to obtain conventional PI-controller gains.

In this study, PI controller is proposed for the load frequency control scheme of two area interconnected hydro-thermal power systems is incorporated with both non-linearities (GDB and GRC). The simulation results show that the dynamic performance over conventional PI-controller even with the consideration of non-linearities of the system is significantly improved. It provides quality and reliable electric power supply.

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