IMPROVEMENT OF DYNAMIC PERFORMANCE OF THREE AREA HYDRO-THERMAL SYSTEM INTERCONNECTED WITH AC-TIE LINE PARALLEL WITH HVDC LINK IN DEREGULATED ENVIRONMENT

L. ShanmukhaRao[1], N. Venkata Ramana[2]
[1] E.E.E Department, Dhanekula Institute of Engineering & Technology, Ganguru, Vijayawada, AP, India.
[2] E.E.E Department, JNTU Jagityal, AP, India.

ABSTRACT

This paper presents analysis on Improvement of dynamic performance of a three-area Hydro-thermal system interconnected with AC tie-line parallel with HVDC link when subjected to parametric uncertainties when compared to a three-area Hydro-thermal system interconnected with AC tie-line. In this paper three areas consists of one Hydro and one thermal power plant are considered.AC-Tie line parallel with HVDC link is used as a system interconnection between all the three areas. Open transmission access and the evolution of more socialized companies for generation, transmission and distribution affects the formulation of Automatic Generation Control (AGC) problem. So, the traditional three area system is modified and taken into the account the effect of bilateral contracts on the dynamics.

KEYWORDS: *AGC, HVDC link, Hydro-thermal, Open Market*

NOMENCLATURE

ACE	Area Control Error
AGC	Automatic Generation Control
APF	Area Participation factor
CPF	Contact Participation factor
DISCOs	Distribution companies
GENCOs	Generation companies
B	Frequency Bias
R	Speed Regulation
LFC	Load Frequency Control
DPM	DISCO Participation Matrix
T_t	Turbine Time Constant
T_g	Governor Time Constant
T_p	Power system equivalent time constant
T_{Dc}	Delay in establishing the DC current after a step change.
K_p	Power system equivalent gain
ISO	Independent System Operator
HVDC link	High Voltage Direct Current link
T	Tie line synchronizing coefficient
VIU	Vertically integrated utility
F	Area Frequency
Δ	Deviation from nominal valve

P_m	Turbine power output
P_G	Governor Output
K_{dc}	Gain of HVDC link

I. INTRODUCTION

The normal operation of an interconnected multi-area power system requires that each area maintain the load and generation balance. This is normally achieved by means of an automatic generation controller (AGC). AGC tries to achieve this balance by maintaining the system frequency and the tie line flows at their scheduled values. The AGC action is guided by the area control error (ACE), which is a function of system frequency and tie line flows. The ACE represents a mismatch between area load and generation taking into account any interchange agreement with the neighboring areas. The ACE for the i th area is defined as

$$\mathbf{ACE=\Delta P_{tie} + B_{I}\,\Delta f} \qquad \mathbf{(1)}$$

Where $\mathbf{\Delta P_{tie} = P_{tie\ actual} - P_{tie\ scheduled}}$ and P_{tie} is the net tie line flow.
$\mathbf{\Delta f = f_{actual} - f_{scheduled}}$ and f is the system frequency. $\mathbf{B_i}$ is referred to as the frequency bias factor. This control philosophy is widely used and is generally referred to as the tie line bias control. AGC studies are generally carried out using simulation models. This model has been used to study the AGC for three area reheat hydro-thermal system [4–6] and hydro thermal system [7]. It appears that the studies carried out so far are limited to only thermal or Hydro systems. Even though the interconnected hydro and thermal systems are quite common. AGC of such systems does not seem to have studied so far. This paper presents a study of the AGC for a three-area Hydro-Thermal system.
In the power system, any sudden load change causes the deviation of tie-line exchanges and the frequency fluctuations [9]. So, AGC is very important for supplying electric power with good quality. Now-a-days, the electric power industry is moving towards an open market deregulated environment in which consumers have an opportunity to select among different competing suppliers of electric energy. Deregulation is the collection of unbundled rules and economic incentives that governments set up to control and drive the electric power industry. Power system under open market scenario[23] consists of generation companies (GENCOs), distribution companies (DISCOs), and transmission companies (TRANSCOs) and independent system operator (ISO). In deregulated environment, [25] each component has to be modeled differently because each component plays an important role. There are crucial differences between the AGC operation in a vertically integrated industry (conventional case) and horizontally integrated industry (new case). In the reconstructed power system after deregulation, operation, simulation and optimization have to be reformulated although basic approach to AGC has been kept the same. In this case, a DISCO can contract individually with any GENCO for power and these transactions are made under the supervision of ISO. To understand how these contracts are implemented, DISCO participation matrix concept is used. The information flow of the contracts is superimposed on the traditional AGC system. In the literature, there are some research studies on deregulated AGC.
The power system operation in an interconnected [3] grid system improves system security and economy of operation. In addition, the interconnection permits the utilities to make economic transfers and takes the advantages of the most economical sources of power. Each power system within such a pool operates technically and economically, but contractually tied to other pool members in respect to certain generation and scheduling features. To fulfill these contracts, there is a requirement of transmission lines which are capable of exchanging large amounts of power between them over a wide spread area effectively and efficiently. In the early days this purpose was served by AC tie-lines. However, many problems have been faced with AC tie-line interconnections particularly in case of transmission over long distances. These problems have been overcome by the use of asynchronous HVDC link connecting two control areas. By this interconnection with HVDC link, frequency deviation is very low which leads to improvement of quality and continuity of power supply to the customers.
The main objective of this paper is to study the improvement in AGC of three area Hydro-thermal system under deregulated environment when interconnected with AC tie-line in parallel with HVDC link. The performance of this System is compared with that of three area inter connected Hydro-Thermal system using AC tie-line.

II. RESTRUCTURED POWER SYSTEM FOR AGC WITH THREE AREA USING HVDC LINK

A. *Traditional vs. Restructured Scenario*

In the open market environment the vertically integrated utility (VIU) power system no longer exists. Deregulated system consists of [16] GENCOs, DISCOs, transmission companies and independent system operators (ISO). However the common goal is to keep frequency constant. The deregulated system contains two areas. Each area contains two generators and also two discos as shown in fig.1. The block diagram of generalized LFC scheme for a two area deregulated hydro-thermal plants is shown in fig.2. A DISCO can contract individually with any GENCO for power and these transactions are made under the supervision of ISO.

The power system is assumed to contain a hydro and a thermal unit in all the three areas therefore each area includes two GENCOs and also two DISCOs as shown in Fig. 1. The detailed scheme of the system is also given in Fig. 2. In the system, any GENCO in any area may supply both DISCOs in its user pool and DISCOs in other areas through tie-lines allowing electric power to flow between the areas. In another words, for restructured system having several GENCOs and DISCOs, any DISCO may contract with any GENCO in another control area independently. This case is called as ‘‘bilateral transactions’’. The transactions have to be implemented through an independent system operator (ISO). The impartial entity, ISO has to control many of ancillary services, one of which is AGC. In deregulated environment, any DISCO has the liberty to buy power at competitive prices from different GENCOs, which may or may not have contract in the same area as the DISCO. For practice, GENCO–DISCO contract is proposed [4] with ‘DISCO participation matrix’ (DPM). Essentially, DPM gives the participation of a DISCO in contract with a GENCO. In DPM, the number of rows has to be equal to the number of GENCOs and the number of columns has to be equal to the number of DISCOs in the system. Any entry in this matrix is a fraction of total load power contracted by a DISCO toward a GENCO. As a result, the total entries of column belong to DISCO1 of DPM is ∑P1cpij=1. The corresponding DPM to the considered power system having three areas and each of them including two DISCOs and two GENCOs is given as follows:

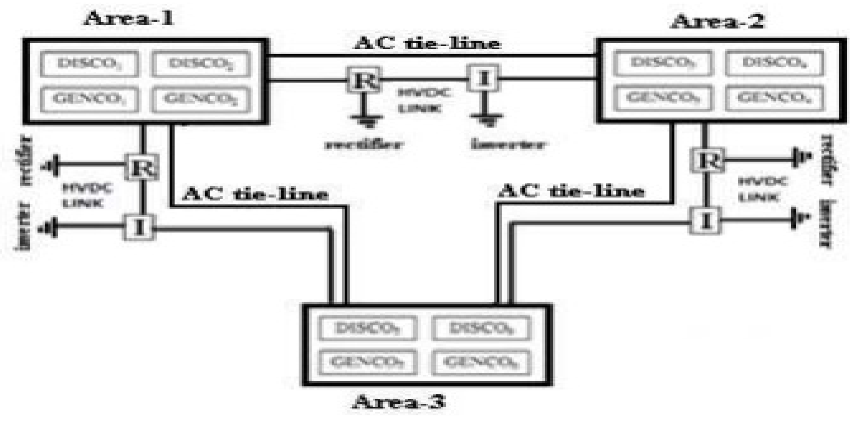

Fig. 1. Configuration of three-area Power System

B. *DISCO Participation Matrix :*

$$DPM = \left[\begin{array}{cc:cc:cc} cp_{11} & cp_{12} & cp_{13} & cp_{14} & cp_{15} & cp_{16} \\ cp_{21} & cp_{22} & cp_{23} & cp_{24} & cp_{25} & cp_{26} \\ \hdashline cp_{31} & cp_{32} & cp_{33} & cp_{34} & cp_{35} & cp_{36} \\ cp_{41} & cp_{42} & cp_{43} & cp_{44} & cp_{45} & cp_{46} \\ \hdashline cp_{51} & cp_{52} & cp_{53} & cp_{54} & cp_{55} & cp_{56} \\ cp_{61} & cp_{62} & cp_{63} & cp_{64} & cp_{65} & cp_{66} \end{array}\right]$$

Where cpfs represent “contract participation factor”. For example, the fraction of the total load power contracted by DISCO1 from GENCO2 is represented by (2, 1) entry,diagonal blocks correspond to demands of the DISCOs in one area to the GENCOs in another area. In the deregulated case, when the load demanded by a DISCO changes, a local load change is observed in the area of the DISCO. Since there are a lot of GENCOs in each area, area control error (ACE) signal must be shared by these GENCOs in proportion to their contributions. The coefficients, which represent this sharing, are called as ''ACE participation factors (apf)'' and

$$\sum_{j=1}^{M} \mathbf{apf_{ij}} = 1 \qquad (1)$$

Where M is the number of GENCOs in each area. As different from conventional AGC systems, any DISCO can demand power from all of the GENCOs. These demands are determined by cpfs, which are contract participation factors, as load of the DISCO. The actual steady power flows on the tie line are given as:

$$\Delta P_{tie1-2\ scheduled} = \sum_{j=1}^{2}\sum_{j=3}^{4} cpfij\ \Delta PL - \sum_{j=3}^{4}\sum_{j=1}^{2} cpfij \qquad (2)$$

$\Delta P_{tie1\text{-}2error} = \Delta P_{tie1\text{-}2\ schedule}$ – *Deviation in power flow in HVDC link – Deviation in AC tie line power flow*

The dotted and dashed lines in Fig. 2 show the demand signals based on the possible contracts between GENCOS and DISCOs that carry information as to which GENCOs have to follow a load demanded by that DISCO. These new information signals were absent in the traditional AGC scheme. As there are many GENCOS in each area, the ACE signal has to be distributed among them due to their ACE participation factor in the AGC task and

$$\sum_{j=1}^{ni} apf_{ji} = 1 \qquad (3)$$

$$d_i = \Delta P_{Loc,i} + \Delta P_{di} \qquad (4)$$

$$\Delta P_{Loc,i} = \sum_{j=1}^{mi} \Delta P_{lj-i} \qquad (5)$$

$$\Delta P_{di} = \sum_{j=1}^{mi} \Delta P_{Ulj-i} \qquad (6)$$

$$\eta_i = \sum_{\substack{j=1 \\ j\neq i}}^{n} T_{ij}\Delta f_j \qquad (7)$$

$$\xi_i = \Delta P_{tie,ik,sch} \sum_{\substack{k=1 \\ k\neq i}}^{n} \Delta P_{tie,ik,sch} \qquad (8)$$

$$\Delta P_{tie,ik,sch} = \sum_{j=1}^{ni}\sum_{t=1}^{mk} apf_{(si+j)(zk+t)}\Delta P_{li-k} - \sum_{j=1}^{nk}\sum_{t=1}^{mi} apf_{(sk+j)(zi+t)}\Delta P_{lj-l} \qquad (9)$$

$$\Delta P_{tie,i-error} = \Delta P_{tie,i-actual} - \xi_i \qquad (10)$$

$$\rho_i = [\rho_{li} \cdots \rho_{ki} \cdot\cdot \rho_{nij}] \qquad (11)$$

$$\rho_{ki} = \sum_{j=i}^{n}\left[\sum_{t=1}^{mj} cpf_{\ (si+k)(zj+t)}\ \Delta P_{lj-j}\right]$$

$$\Delta P_{tm,k-i} = \rho_{ki} + apf_{ki}\sum_{j=1}^{mi}\Delta P_{Ulj-i}\,, k = 1,2\ \ldots, n_i \qquad (12)$$

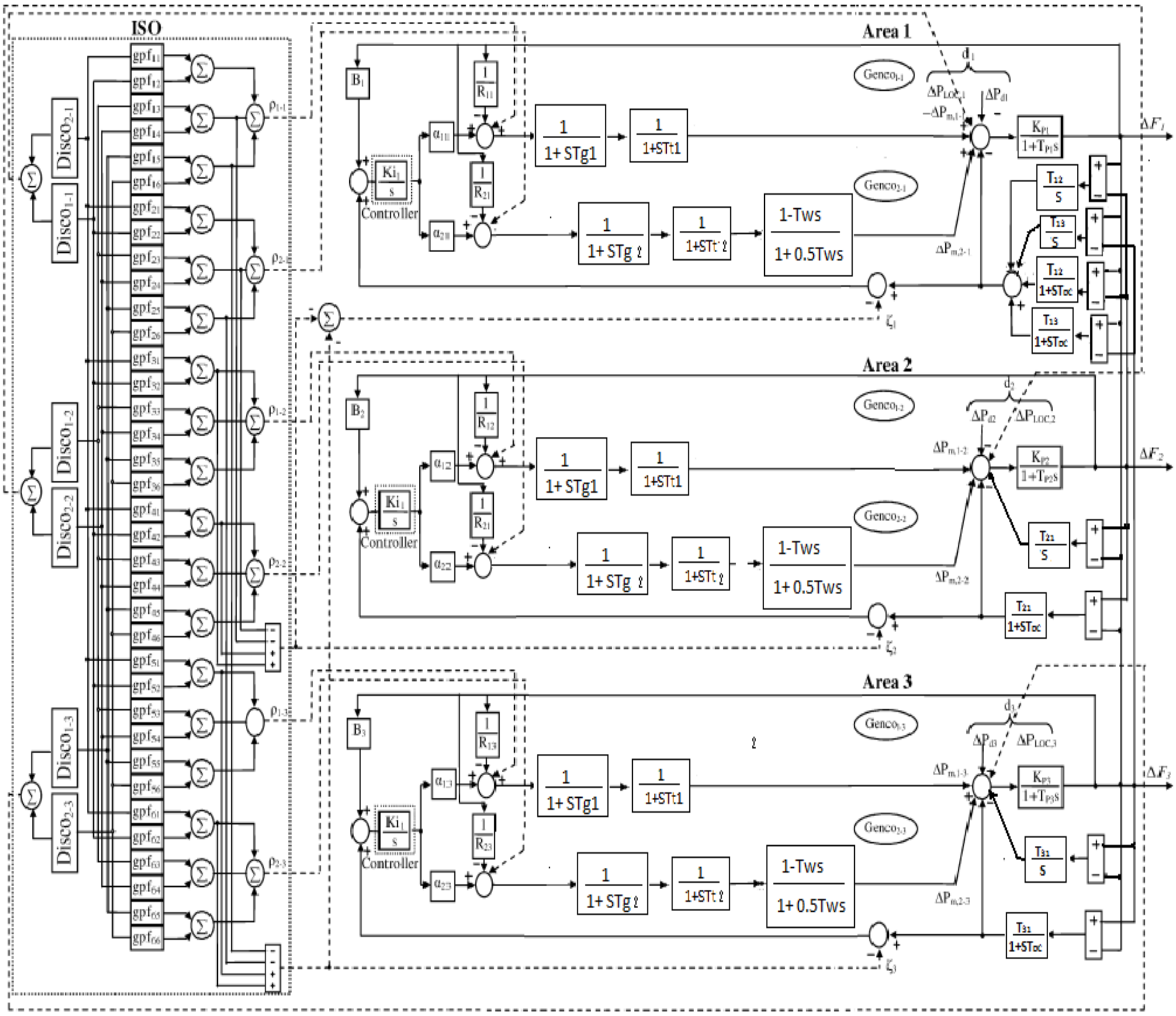

Fig. 2. Modified Three-Area AGC System in a Deregulated Environment interconnected with AC tie-line parallel with HVDC link

III. Mathematical Model of HVDC Link

For a two terminal DC link, with the response type controller model, an alternative representation of DC network is to use a transfer function instead of a resistance.

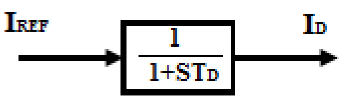

Fig. 3. Transfer Function of HVDC link

In this case, the time constant T_d represents the delay in establishing the DC current after a step change in the order is given.

IV. Simulation Results

Each control area of the deregulated power system is connected to another control area through an AC tie-line parallel with HVDC link as given in figure 2. To illustrate the robustness of the proposed control strategy against parametric uncertainties and contract variations, simulations are performed for three scenarios of possible contracts under various operating conditions and large load demands.

Contact scenario:

In this scenario, DISCOs have the freedom to contract with any GENCO in their and other areas so that the entire DISCOs contract with the GENCOs for power based on following DPM

$$DPM = \begin{bmatrix} 0.3 & 0.25 & 0 & 0.4 & 0.1 & 0.6 \\ 0.2 & 0.15 & 0 & 0.2 & 0.1 & 0 \\ 0 & 0.15 & 0 & 0.2 & 0.2 & 0 \\ 0.2 & 0.15 & 1 & 0 & 0.2 & 0.4 \\ 0.2 & 0.15 & 0 & 0.2 & 0.2 & 0 \\ 0.1 & 0.15 & 0 & 0 & 0.2 & 0 \end{bmatrix}$$

It is considered that each DISCO demands 0.1puMW total power from other GENCOs as defined by entities in DPM and these GENCOs participates in AGC based on the following *apfs.*

$$apf_1 = 0.6,\ apf_2 = 1 - apf_1 = 0.4$$

$$apf_3 = 0.5,\ apf_4 = 1 - apf_3 = 0.5$$

In steady state any GENCO generation must match the required load of the DISCOs in contact with it. It is expressed as:

$$\Delta P_{mi} = \sum_j^j cpfij\, \Delta P_{Lj} \tag{13}$$

So, for this scenario we have

$$\Delta P_{m1} = 0.5(0.1) + 0.25(0.1) + 0.3(0.1) + 0.3(0.1) = 0.135puMW$$
$$\Delta P_{m2} = 0.065puMW$$
$$\Delta P_{m3} = 0.115puMW$$
$$\Delta P_{m4} = 0.085puMW$$

The simulation results for this case are given in the following figures .By using the AC tie-line Parallel with HVDC link for interconnecting the areas, frequency deviation of each control area, power flow through HVDC link and power flow through AC tie line has a good improvement in dynamic response when compared to two area Hydro-Thermal system interconnected with AC tie-line.

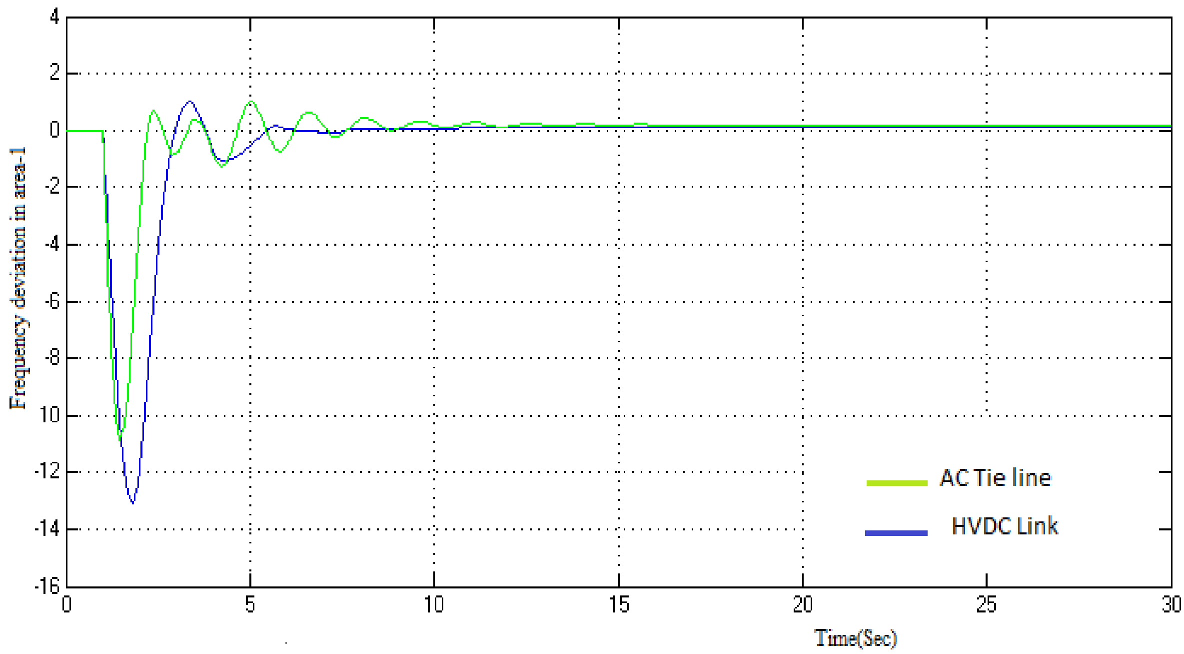

Fig. 4. Change in frequency in area-1.

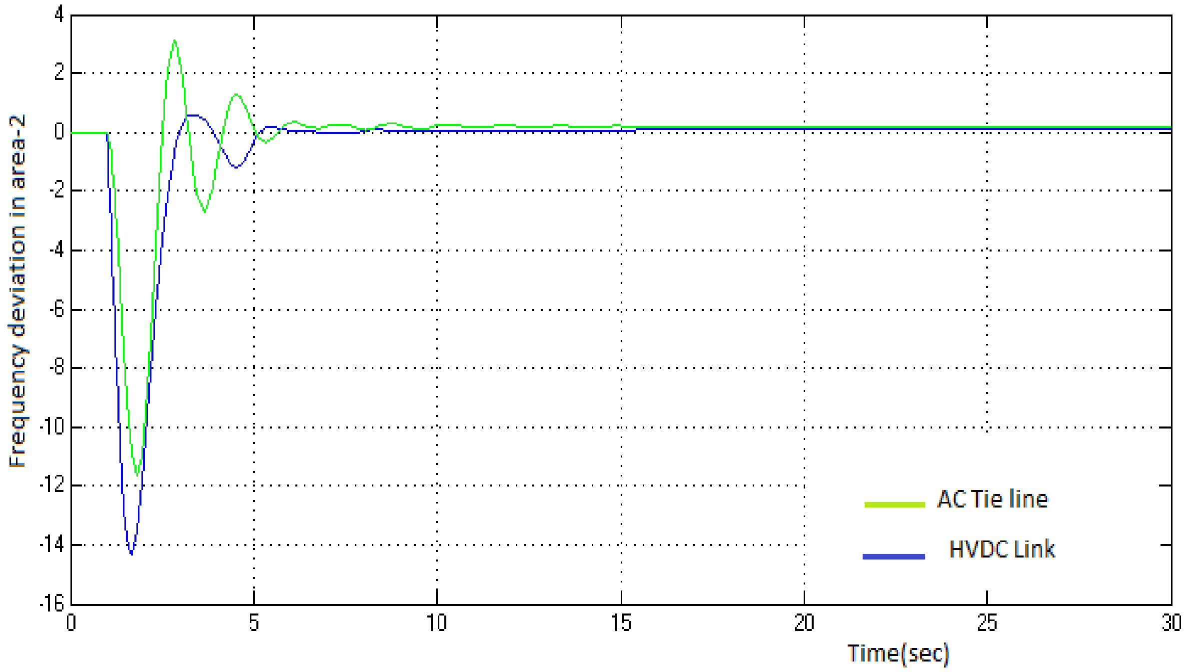

Fig. 5. Change in frequency in area-2.

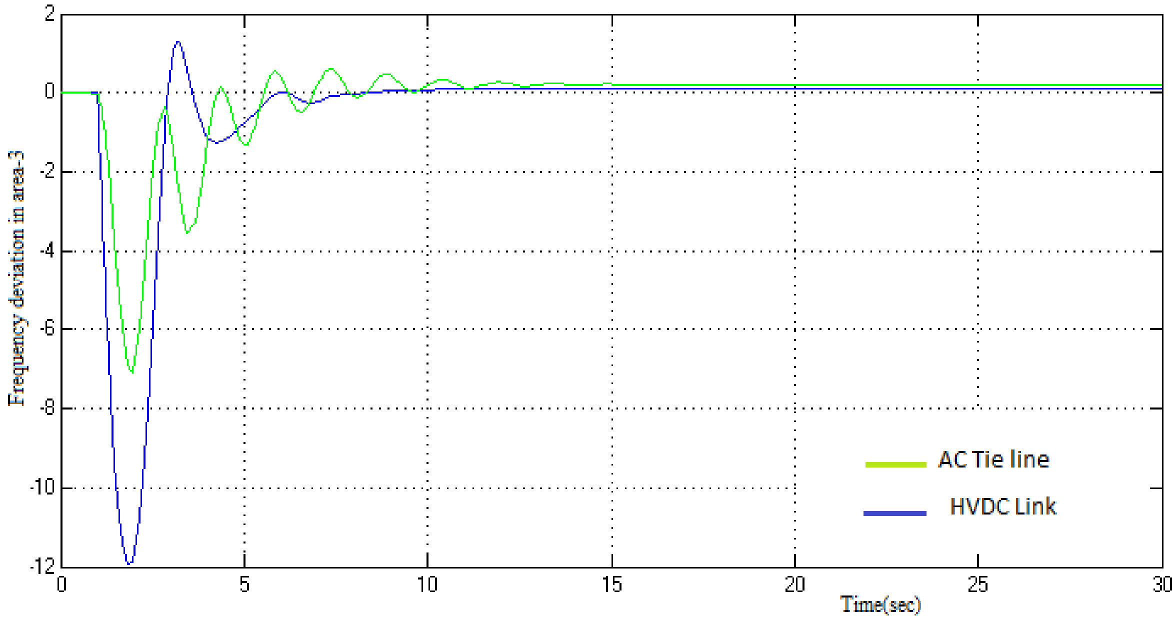

Fig. 6. Change in frequency in area-3.

V. CONCLUSIONS

In this paper load frequency control of power system in a Deregulated environment including bilateral contacts has been studied for a three area Hydro-Thermal system interconnected with AC tie-line parallel with HVDC link. The dynamic performance of the system due to sudden load disturbance in 3-area power system under deregulated environment interconnected with AC tie-line parallel with HVDC link has been studied comprehensively. From the simulation results, it is observed that the dynamic response of three-area interconnected hydro-thermal plants through AC-tie line is sluggish and degraded when compared to the dynamic response of three area interconnected hydro-thermal power plants connected through an AC tie-line parallel with HVDC link. The dynamic response of three-area Hydro-Thermal power system with AC tie-line parallel with HVDC link has been improved compared to dynamic response of same system with AC tie-line.

APPENDIX

Table 1: Genco parameters

GENCOs parameters	Area1		Area2		Area3	
	Genco-1	Genco-2	Genco-3	Genco-4	Genco-5	Genco-6
T_T(S)	0.32	0.30	0.03	0.32	0.30	0.03
T_g(s)	0.06	0.08	0.06	0.07	0.08	0.06
R(Hz/pu)	2.4	2.5	2.5	2.7	2.5	2.5

Table 2: Control Area Parameters

Control Area Parameters	Area-1	Area-2
$K_{p\ (pu/Hz)}$	102	102
T_p(s)	20	25
$B_{(pu/Hz)}$	0.425	0.396
K_{dc}	1	1

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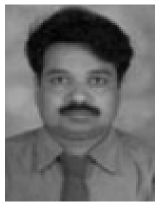
AUTHORS

L ShanmukhaRao received the Bachelor in Electrical and Electronics Engineering degree from the Kakatiya University Warangal. A.P. in 2006 and the Master degree in Electrical Power engineering from the JNTU, Hyderabad in 2006. He is currently pursuing his Ph.D. degree with the Department of Electrical Engineering, JNTUH-Hyderabad. His research interests include Power System Operation and Control. He is currently working as an Associate Professor at Dhanekula Institute of Engineering &Technology, Ganguru, Vijayawada, Krishna District, AP, India.



N. Venkata Ramana received his M. Tech from. S.V. University, India in 1991 and Ph.D. in Electrical Engineering from Jawaharlal Nehru Technological University (J.N.T.U), Hyderabad, India in Jan' 2005, His main research interests includes Power System Modeling and Control. He authored 2 books on power systems and published 20 research papers in national and international journals and attended 10 international conferences. He is currently Professor at J.N.T.U. College of Engineering, Jagityal, Karimnagar District. A.P., India.