IMPROVEMENT OF DYNAMIC PERFORMANCE OF THREE-AREA THERMAL SYSTEM UNDER DEREGULATED ENVIRONMENT USING HVDC LINK

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ABSTRACT

This paper presents an analysis on dynamic performance of a three-area thermal system interconnected with HVDC links when subjected to parametric uncertainties. In this paper all the three areas consists of thermal power plants. The HVDC link is used as a system interconnection between all the three areas. Open transmission access and the evolution of more socialised companies for generation, transmission and distribution affects the formulation of Automatic Generation Control (AGC) problem. So, the traditional three area system is modified to take into account the effect of bilateral contracts on the dynamics. It has been observed that the dynamic response of three-area interconnected thermal plants through tie-line is sluggish and degraded when compared to the dynamic response of three area interconnected thermal power plants connected through a DC link.

KEYWORDS: *AGC, HVDC link, Deregulated Power system.*

I. NOMENCLATURE

ISO	Independent System Operator
VIU	Vertically Integrated Utilities
DISCOs	Distribution Companies
GENCOs	Generation Companies
TRANSCO	Transmission system
F	Area frequency
P	Tie net tie line power flow
P_T	Turbine power
P_V	Governor valve position
P_C	Governor set point
ACE	Area control error
apf	Area control error Participation factor
cpf	Contract Participation Factor
DPM	DISCO Participation Matrix
Δ	Deviation from nominal value
K_P	Subsystem equivalent gain
T_P	Subsystem equivalent time constant
T_T	Turbine time constant
T_H	Governor Time constant
T_{DC}	Time delay of DC Link
R	Droop characteristic
B	Frequency bias
T_{ij}	Tie line synchronizing coefficient between areas I and j
P_d	Area load disturbance
P_{Lji}	Contracted demand of DISCO j in area i
P_{Ulji}	Un-contracted demand of DISCO j in area i
P_{Mji}	Power generation of GENCOS j in area i
P_{Loc}	Total local demand
g	Area interface
f	Scheduled power tie line power flow deviation (DPtie,sch)

II. INTRODUCTION

In the power system, any sudden load change causes the deviation of tie-line exchanges and the frequency fluctuations. 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 consists of generation companies (GENCOs), distribution companies (DISCOs), and transmission companies (TRANSCOs) and independent system operator (ISO). In deregulated environment, each component has to be modelled 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 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 fulfil 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.

In deregulated system, the structure of power system is modified in such a way that would allow the evolution of more industries for generation (GENCOs), Transmission (TRANSCOs) and Distribution (DISCOs).

The main objective of this paper is to develop a three area thermal system under deregulated environment by incorporating the bilateral contracts on the system. Also, to improve the dynamic performance of the system, the conventional EHVAC tie line is replaced with the HVDC link connecting two areas.

III. RESTRUCTURED SYSTEM FOR AGC WITH THREE AREAS

Each control area consists of two thermal plants and also two DISCOs as shown in Fig. 1. The detailed schematic diagram of three area thermal system is also given in Fig. 3. In this open market scenario, any GENCO in one area may supply DISCOs in the same area as well as DISCOs in other areas through asynchronous HVDC links allowing power transfer between the areas. In other words, for restructured system having several GENCOS and DISCOs, any DISCO may contract with any GENCO in another control area independently. This is called as ‘‘bilateral transaction’’. The transactions have to be carried out through an independent system operator (ISO). The main purpose of ISO is to control many ancillary services, one of which is AGC. In deregulated environment, any DISCO has the liberty to purchase MW power at competitive price from different GENCOs, which may or may not have contract with the same area as the DISCO. For practice, GENCO–DISCO contracts are represented with ‘DISCO participation matrix’ (DPM). Essentially, DPM gives the participation of a DISCO in contract with a GENCO. In DPM, the number of rows is equal to the number of GENCOs and the number of columns is equal to the number of DISCOs in the system. Any entry of this matrix is a fraction of total load power contracted by a DISCO toward a GENCO. As a result, total of entries of column belong to DISCO1 of DPM is $\sum cpf_{ij}=1$. The corresponding DPM to the considered power system having three areas and each of them including two DISCOs and two GENCOSs is given as follows:

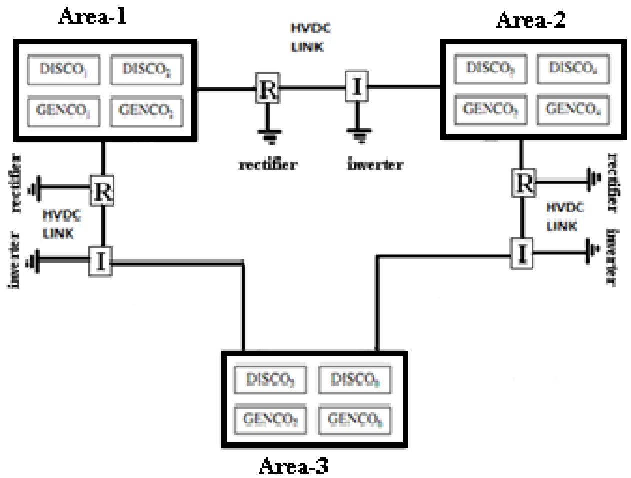

Fig. 1. Configuration of three-area Power System

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

Where, cpf represents ''contract participation factor''. For example, the fraction of the total load power contracted by DISCO1 from GENCO2 is represented by (2, 1) entry. Off-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. In the equations of the system given in Appendix A, such load changes, ΔP_{Li} (i =1... 6), are contained. 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 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 dotted and dashed lines 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

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IV. MATHEMATICAL MODEL OF HVDC LINK AS A CONSTANT CURRENT CONTROLLER

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.2. Transfer function of HVDC

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

V. SIMULATION RESULTS

Each control area of the deregulated power system is connected to another control area through a HVDC link as given in Section 3. To illustrate the improvement of dynamic response of the three area deregulated system with HVDC link compared to the three area deregulated system with tie-line under contract variations. Simulation results are studied for two contract variation scenarios.
In deregulated environment, the DISCO participation matrix (DPM) is chosen on the basis of open market strategy. Change of DPM changes the generation schedule of all the GENCOs and hence the system behavior 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 contact variations. The two different DPMs considered for the present investigations are given below as A and B

A.Scenario-1:

In this scenario DISCO has the freedom to contract with any GENCOs or other areas. So, all the DISCOs contracts with the GENCOs 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 GENCO participates in AGC in each control area as defined by following:
ap_1 =0.5, ap2= 1-ap1=0.5, ap3=0.5,
ap4= 1-ap3=0.5, ap5=0.6, ap6= 1-ap5=0.4.

ACE participation factor affects only transient behaviour of the system. It does not affect the steady state behaviour

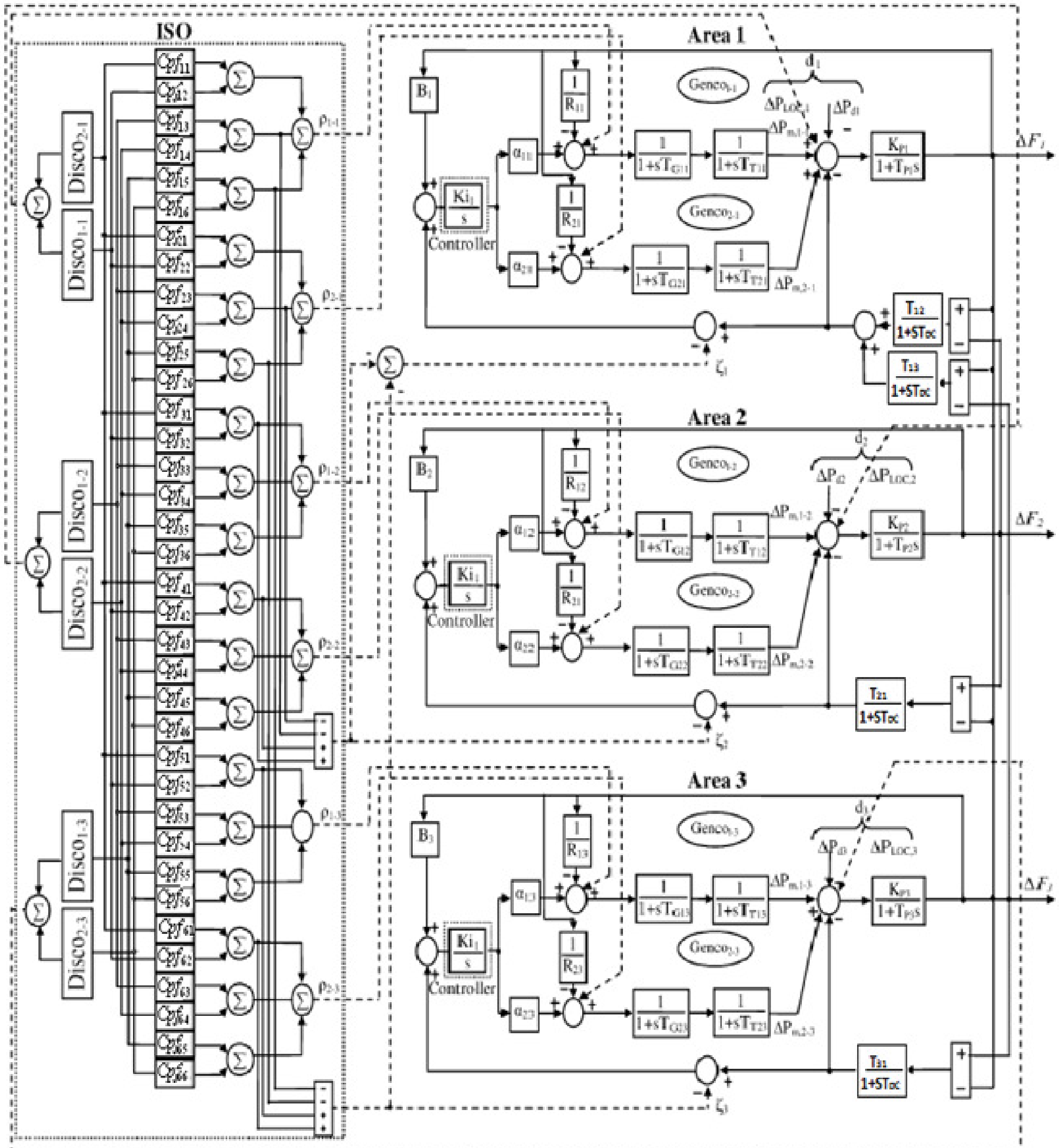
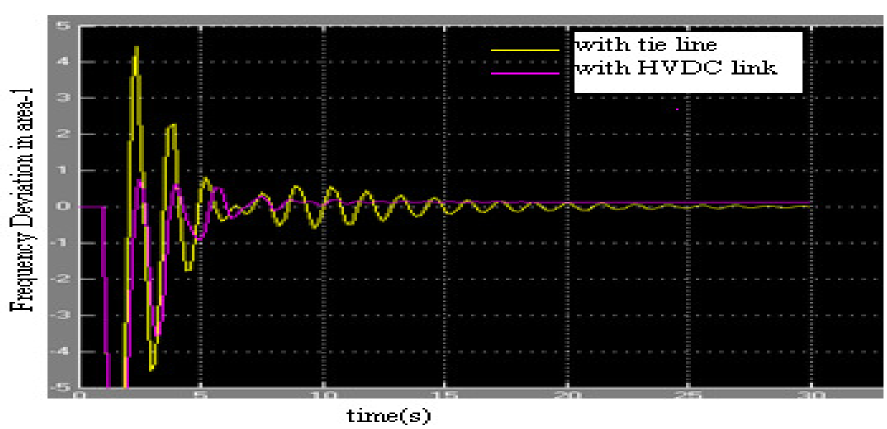
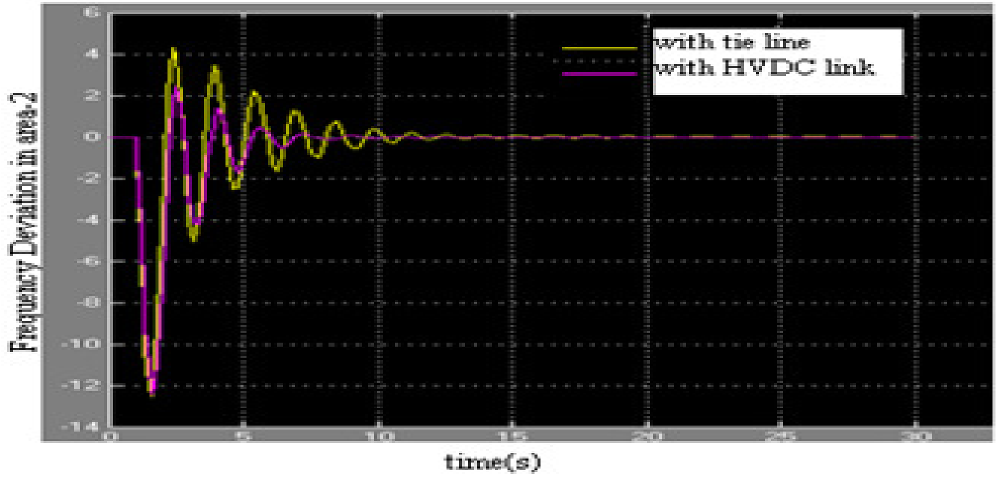


Fig .3.Three-Area Thermal System under Deregulated environment with HVDC link.

(a)



(b)



(c)

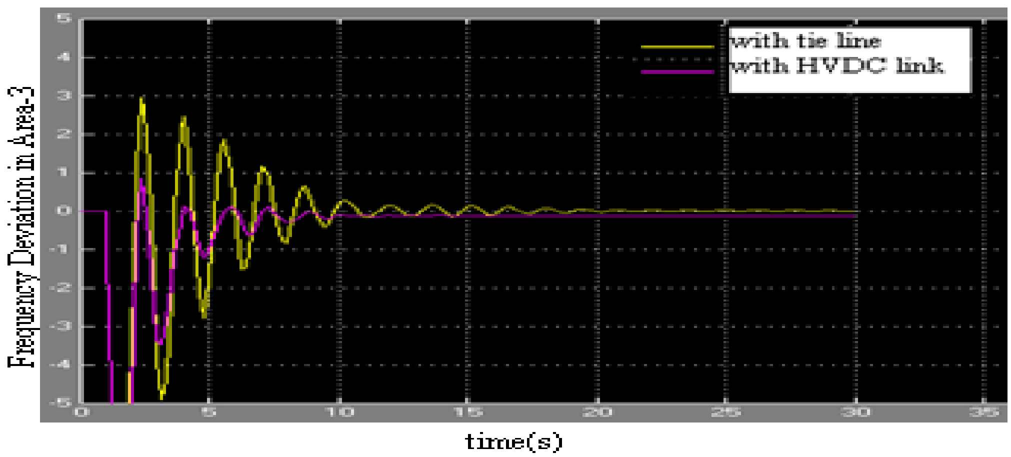


Fig.4. (a) Frequency deviation in area-1(rad/sec), (b) Frequency deviation in area- 2(rad/sec), (c) Frequency deviation in area-3(rad/sec).

b. Scenario-2:

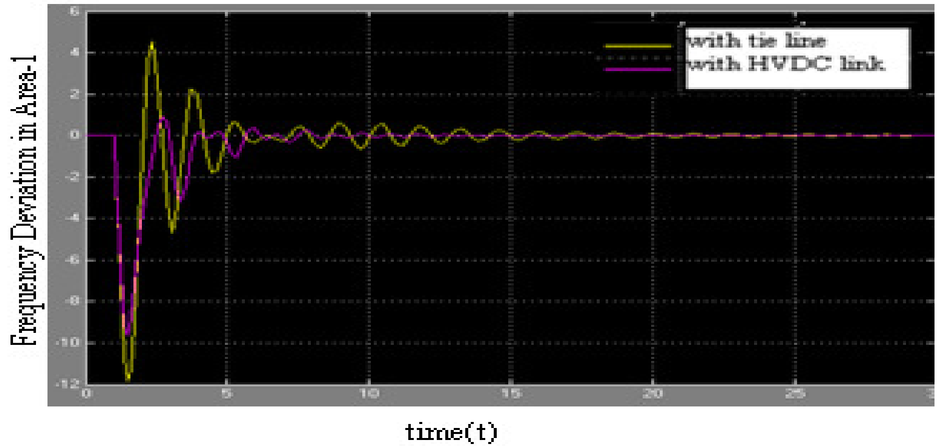
In this case all GENCOs in each control area participate in AGC. DPM matrix is assumed to be

$$DPM = \begin{bmatrix} 0.25 & 0 & 0.25 & 0 & 0.5 & 0 \\ 0.5 & 0.25 & 0 & 0.25 & 0 & 0 \\ 0 & 0.5 & 0.25 & 0 & 0 & 0 \\ 0.25 & 0 & 0.5 & 0.75 & 0 & 0 \\ 0 & 0.25 & 0 & 0 & 0.5 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

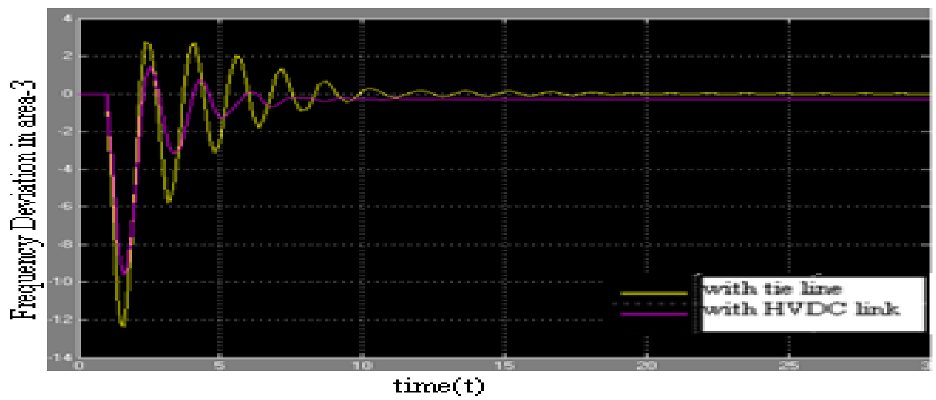
In this scenario, it is considered that, each GENCO participates in AGC in each control area as defined by following:

ap_1 =0.3, ap2= 1-ap1=0.7, ap3=0.3, ap4= 1-ap3=0.7, ap5=0.3, ap6= 1-ap5=0.7.

(a)



(b)



(c)

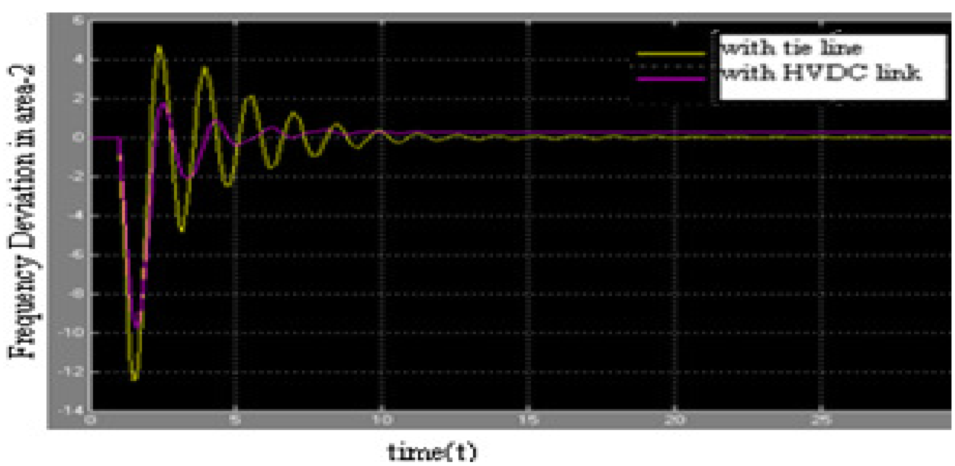


Fig.5. (a) Frequency deviation in area-1(rad/sec), (b) Frequency deviation in area- 2(rad/sec), (c) Frequency deviation in area-3(rad/sec).

VI. CONCLUSION

The dynamic performance of the system due to sudden load disturbance in 3-area interconnected power system under deregulated environment with HVDC link has been studied comprehensively. The power system model with thermal power plants is considered for the study in deregulated environment. The dynamic response of three-area power system with HVDC link has been improved compared to dynamic response of same system with AC tie-line. With HVDC link, the dynamic oscillations die out quickly and system comes to steady state with negligible frequency deviation. So, it may be concluded that HVDC link can be a new ancillary service for stabilization of frequencies in the three-area deregulated environment.

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