ISSN 1 746-7233, England, UK
World Journal of Modelling and Simulation
Vol. 4 (2008) No. 2, pp. 153-160

Improvement of dynamic performance of hydrothermal system under open market scenario using asynchronous tie-lines

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(*Received September 26 2007, accepted December 11 2007*)

Abstract. This paper presents an analysis on dynamic performance of a two-area hydrothermal system interconnected via parallel ac/dc transmission links when subjected to parametric uncertainties. In this paper area-1 consists of thermal power plant whereas area-2 consists of hydro power plant. The dc link is used as system interconnection in parallel with ac tie-line. The dc links is considered to be operating in constant current control mode and the power flow deviation through dc link is modelled based on frequency deviation at rectifier end. Open transmission access and the evolving of more socialized companies for generation, transmission and distribution affects the formulation of Automatic Generation Control (AGC) problem. So the traditional AGC two-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 interconnected hydro thermal systems under open market scenario is sluggish and degraded in all aspects of response qualities. The degradation in system dynamic performance can be compensated effectively using dc link in parallel with ac tie-line and the same have been presented using MATLAB/SIMULINK.

Keywords: AGC, hydrothermal system, open market, HVDC transmission link, asynchronous tie-lines

1 Introduction

Large scale power systems are normally composed of control areas or regions representing coherent groups of generators. In a practically interconnected power system, the generation normally comprises of a mix of thermal, hydro, nuclear and gas power generation. However, owing to their high efficiency, nuclear plants are usually kept at base load close to their maximum output with no participation in the system automatic generation control (AGC). Gas plants are used to meet peak demands only. Thus the natural choice for AGC falls on either thermal or hydro units. Literature survey shows that most of earlier works in the area of AGC pertain to interconnected thermal systems and relatively lesser attention has been devoted to the AGC of interconnected hydro-thermal system involving thermal and hydro subsystem of widely different characteristics. Concordia and Kirchmayer[5] have studied the AGC of a hydro-thermal system considering non-reheat type thermal system neglecting generation rate constraints. Kothari, Kaul, Nanda[8] have investigated the AGC problem of a hydro-thermal system provided with integral type supplementary controllers. The model uses continuous mode strategy, where both system and controllers are assumed to work in the continuous mode. It is to be appreciated that in a realistic situation, the system works in the continuous mode whereas the controllers work in the discrete mode. Perhaps Nanda, Kothari and Satsangi[12] are the first to present comprehensive analysis of AGC of an interconnected hydrothermal system in continuous-discrete mode with classical controllers.

The operation of power system as an interconnected system usually leads to improved system security and economy of operation[11]. In addition, the interconnection permits the utilities to make economy transfers and thus takes the advantage of the most economical sources of power. Each power system within such a power pool operates technically and economically independently, but is contractually tied to the other pool members in respect to certain generation and scheduling features. Therefore, to fulfill the contracts, there is a further requirement of such transmission links which are capable of exchanging the large chunk of electrical power between widely spread power pools effectively and efficiently. Till seventies, this requirement was fulfilled by EHVAC (Extra high voltage AC) transmission systems. However, many problems have been identified with EHVAC interconnection between the power systems particularly using for long distance transmission. One of the major applications of HVDC (High voltage DC) transmission is operating a HVDC link in parallel with an EHVAC link interconnecting two control areas[3, 14]. With these developments, the power utilities are capable to fulfill the requirements of good quality of electric power supply to consumers to some extent but on the other hand the operational and control aspects of these systems are subjected for their review.

Under open market system (deregulation) the power system structure changed in such a way that would allow the evolving of more specialized industries for generation (Genco), transmission (Transco) and distribution (Disco). A detailed study on the control of generation in deregulated power systems (open market) is given in [15]. The concept of independent system operator (ISO) as an unbiased coordinator to balance reliability with economics has also emerged[9, 10]. The assessment of Automatic Generation control in a deregulated environment is given in detail in [2, 6] and also provides a detailed review over this issue and explains how an AGC system could be simulated after deregulation.

The main objective of this paper is to develop a two area hydrothermal system under open market scenario by incorporating the bilateral contracts on the system. Also to improve the dynamic performance of the system, a HVDC link in parallel with the EHVAC link interconnecting two control areas is implemented.

2 Two area power system model

The two area model used in this paper is as follows:

· It is a two-area interconnected system under open market scenario consisting of thermal and hydro units.

· The two areas are interconnected via EHVAC transmission line in parallel with HVDC link.

The single line diagram of power system model under consideration is shown in Fig. 1,

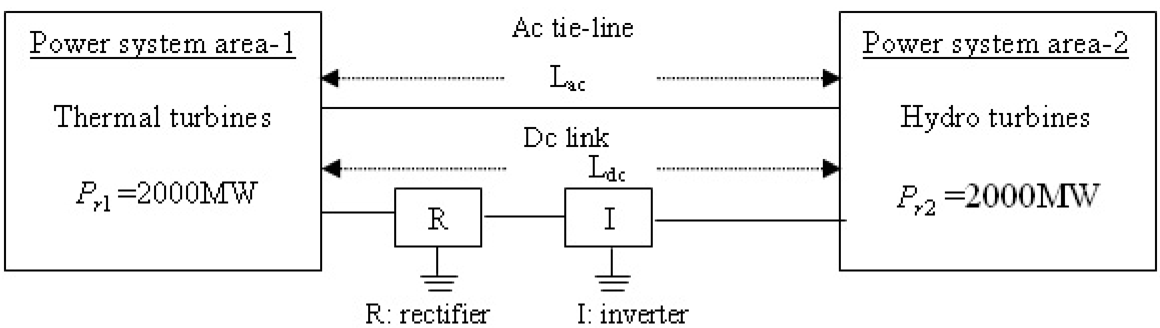

Fig. 1. Two area interconnected power system

The rated power of each area in the Fig. 1 is 2000 MW. The transmission links are considered as long transmission lines specifically of length (L_{ac} and L_{dc}) greater than break even distance length of the EHVAC and HVDC transmission lines[13]. The distance normally used as break even distance is about 600 km. The compatible HVDC transmission system voltage level for 400 kV EHVAC transmission system may be a monopolar HVDC line of 400 kV.

3 Open market system

As there are several Gencos and Discos in the open market structure, a Disco has the freedom to have a contract with any Genco for transaction of power. A Disco may have a contract with a Genco in another control area. Such transactions are called “bilateral transactions.” All the transactions have to be cleared through an impartial entity called an independent system operator (ISO). The ISO has to control a number of so-called “ancillary services”, one of which is AGC.

3.1 Block diagram formulation

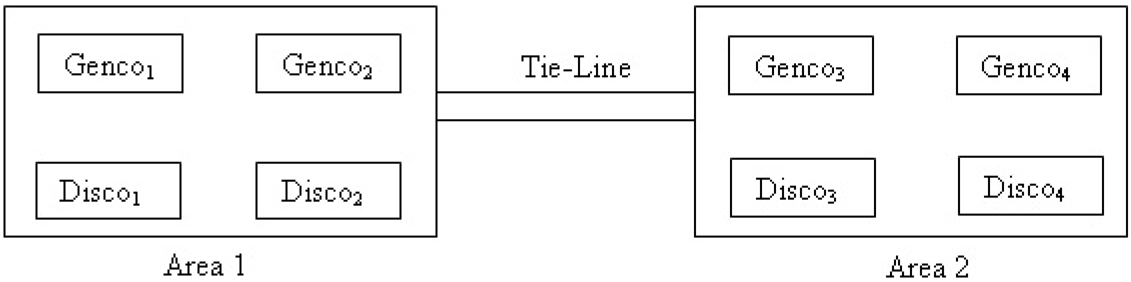

Fig. 2. Schematic of two area system under open market system

In this section, we formulate the block diagram for a two-area AGC system in the deregulated scenario as shown in Fig. 3. 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 and and should be reflected in the deregulated AGC 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 AGC. Coefficients that distribute ACE to several Gencos are termed as “ACE participation factors”($apf's$). Unlike in the traditional AGC 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. The scheduled steady state power flow on the tie line is given as

$\triangle P_{tie1-2,actual} = \triangle P_{tie12}(s) +$ (demand of Discos in area 2 from Gencos in area 1)
- (demand of Discos in area 1 from Gencos in area2)

3.2 Disco participation matrix

In the open market environment, Gencos sell power to various Discos at competitive prices. Thus, Discos have the liberty to choose the Gencos for contracts. They may or may not have contracts with the Gencos in their own area. This makes various combinations of Genco-Disco contracts possible in practice. The concept of “Disco participation matrix” (DPM) is introduced to make the visualization of contracts easier. DPM is a matrix with the number of rows equal to the number of Gencos and the number of columns equal to the number of Discos in the system. Each entry in this matrix can be thought of as a fraction of a total load contracted by a Disco (column) toward a Genco (row). Thus, the ijth entry corresponds to the fraction of the total load power contracted by Disco ‘j’ from a Genco ‘i’. The sum of all the entries in a column in this matrix is unity. DPM shows the participation of a Disco in a contract with a Genco; hence the name “Disco participation matrix”. Consider a two-area system in which each area has two Gencos and two Discos in it. Let Genco1, Genco2, Disco1, and Disco2 be in area I and Genco3, Genco4, Disco3, and Disco4 be in area II as shown in Fig. 2. The corresponding DPM will become

$$\text{DPM} = \begin{bmatrix} cpf_{11} & cpf_{12} & cpf_{13} & cpf_{14} \\ cpf_{21} & cpf_{22} & cpf_{23} & cpf_{24} \\ cpf_{31} & cpf_{32} & cpf_{33} & cpf_{34} \\ cpf_{41} & cpf_{42} & cpf_{43} & cpf_{44} \end{bmatrix}$$

Where 'cpf'refers to "contract participation factor". Suppose that Disco_3 demands 0.1 pu MW power, out of which 0.025 pu MW is demanded from Disco_1, 0.03 pu MW from Disco_2, 0.035 pu MW from Genco3 and 0.01 pu MW from Disco_4. Then column 3 entries in the DPM matrix shown above are easily defined as

$$cpf_P13 = \frac{0.025}{0.1} = 0.25, cpf_{23} = \frac{0.03}{0.1} = 0.3, cpf_P33 = \frac{0.035}{0.1} = 0.35, cpf_P43 = \frac{0.01}{0.1} = 0.1$$

3.3 Strategy of AGC with HVDC link under open market system

The application of linear optimal control theory is one of the most promising approach to cope with AGC problem of interconnected power systems. The advanced versions of optimal control scheme incorporating the integrals ACE as additional state variables were proposed in literature [4, 16] following the work of Elgerd and Fosha[7]. The integral control strategy is found useful in achieving zero steady state error in the frequency of system. Also the system dynamic performance may be enhanced with the implementation of optimal AGC regulators considering the dynamic model of incremental power flow through dc line as control variable. Hence, the present study has been performed using integral control strategy for the design of optimal AGC regulators. The incremental power flow through dc link is considered as an additional control variable with turbine controllers. Two types of interconnections (a) A.C transmission link; and (ii) A.C link in parallel with D.C transmission link are considered between the two areas. The dc link is considered to be operated in constant current control mode. The incremental power flow through dc link is modelled with incremental change in frequency at rectifier end[14].

The AGC system investigated is composed of an interconnection of two areas under open market system. Area 1 comprises of a reheat system and area 2 comprises of hydro system. The detailed transfer function models of speed governors and turbines are discussed and developed in the IEEE committee report on Dynamic models for Steam and Hydro turbines in Power systems[1]. The detailed small perturbation transfer function block diagram model of two area hydrothermal system with HVDC link in parallel with the EHVAC link under open market scenario is shown in Fig. 3.

4 Results and discussions

The proposed concept is applied to a two area hydrothermal thermal system under open market scenario. The simulation has been conducted using Matlab/Simulink. The limiting value of deadband is specified as 0.06% and a specific value of generation rate limitation is 0.1 p.u. per minute [4]. Each Genco participates in AGC as defined by following area participation factors (apfs): apf_1 =0.5, apf_2 =0.25, apf_3 =0.25, apf_4 =0.5, apf_5 =0.25, apf_6 =0.25. Coefficients that distribute ACE to several Gencos are termed as "ACE participation factors" ($apfs$). It should be noted that $\sum_{j=1}^{m} apf_j = 1$,where m is the number of Gencos. The Discos contract with the Gencos as per the following Disco participation matrix. The disco participation matrix(DPM) in this work is taken as follows:

$$\text{DPM} = \begin{bmatrix} 0.1 & 0.0 & 0.3 & 0.4 \\ 0.0 & 0.1 & 0.0 & 0.2 \\ 0.3 & 0.4 & 0.1 & 0.0 \\ 0.2 & 0.0 & 0.2 & 0.1 \end{bmatrix}$$

A step load disturbance of 0.04 pu MW is considered in either of the areas (fig 6-8). Also an additional case is also considered when Contract violation occurs in either area. So in this contact violation an additional load of 0.03 pu MW is considered in both the areas after the time span of 30 sec and 75 sec (fig 9-11). In this contract violation the Gencos which are present in that particular area where the violation has taken place indeed take up that extra load while the remaining generators of other area generate the power which they had

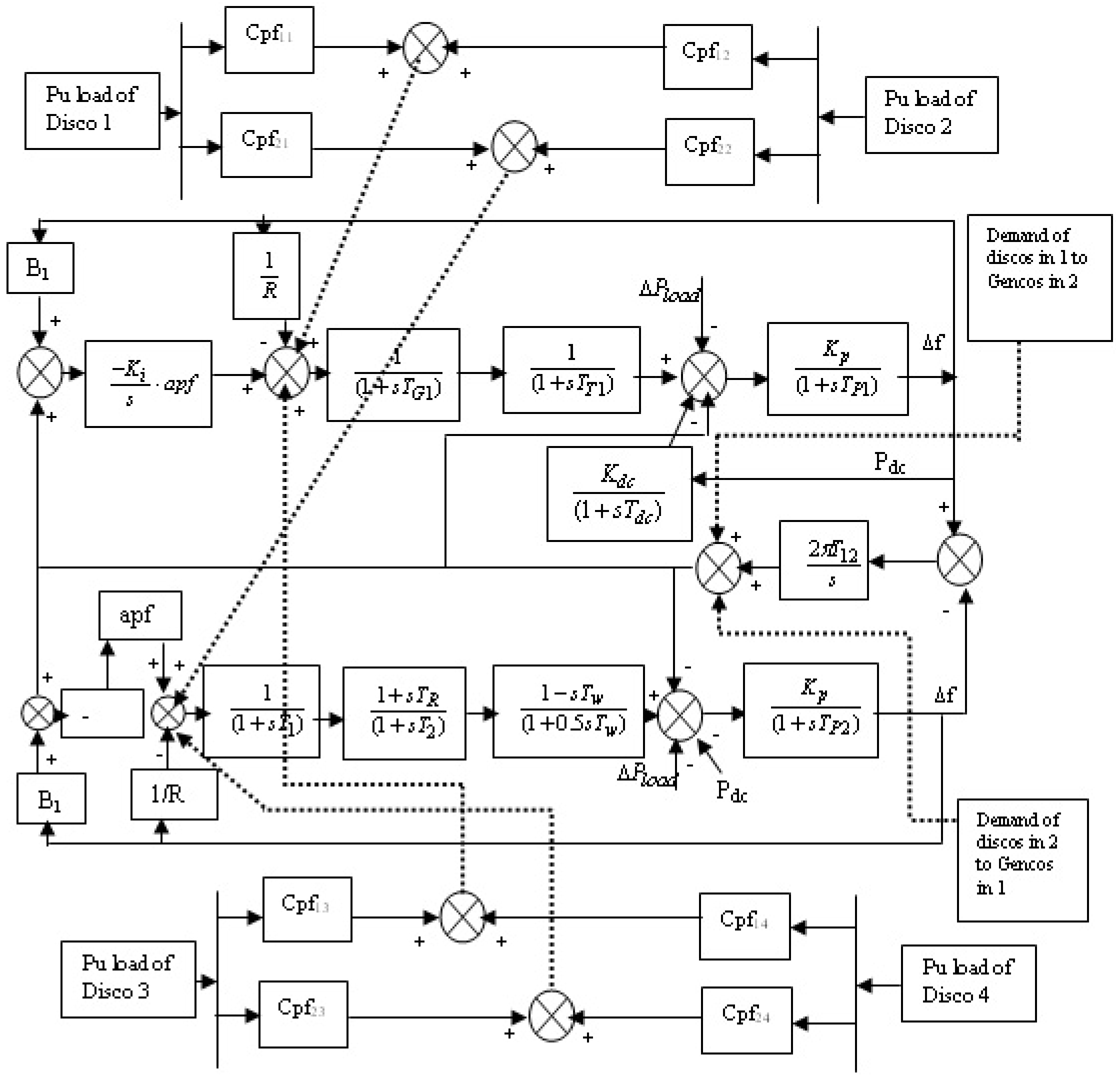

Fig. 3. Two area hydrothermal system under open market system with HVDC link

been generating before. It can also be seen that this contract violation does not affect the systems frequency response and altogether the system comes back to its original state after some disturbance initially.

A performance index which is denoted by $J = \int_0^t (\alpha\Delta f_1^2 + \beta\Delta f_2^2 + \Delta P_{tie12}^2)dt$ is taken into consideration in order to compare between with HVDC link and without HVDC link. A value of 0.65 is considered for both and . Fig 10 shows the comparison between the two cases. It can be seen that using the HVDC link in parallel with the EHVAC link in the two area system, the value of performance index (error values) indeed reduces drastically.

5 Conclusions

The system dynamic performance in the wake of load disturbance in either of the area of interconnected power system under open market scenario with HVDC link has been investigated comprehensively. The power system model with hydro and reheat thermal power plants are considered for the study. The optimal AGC regulators using integral control strategy are designed and their feasibility is studied. The degradation in system dynamic performance of a two interconnected power system under open market can be compensated effectively by incorporating DC link in parallel with AC tie-line as area interconnection between two power system areas. It may be therefore concluded that, the tie-line power flow with HVDC link in parallel with the

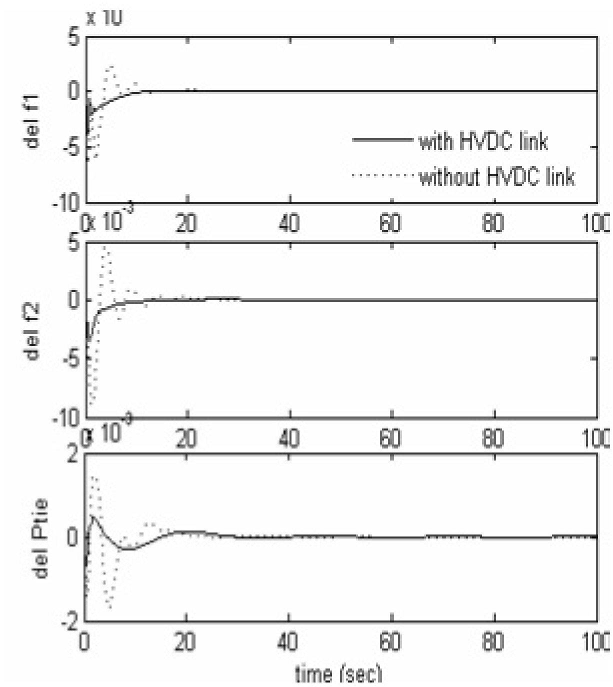

Fig. 4. Variations in area frequencies and tie-line power deviations

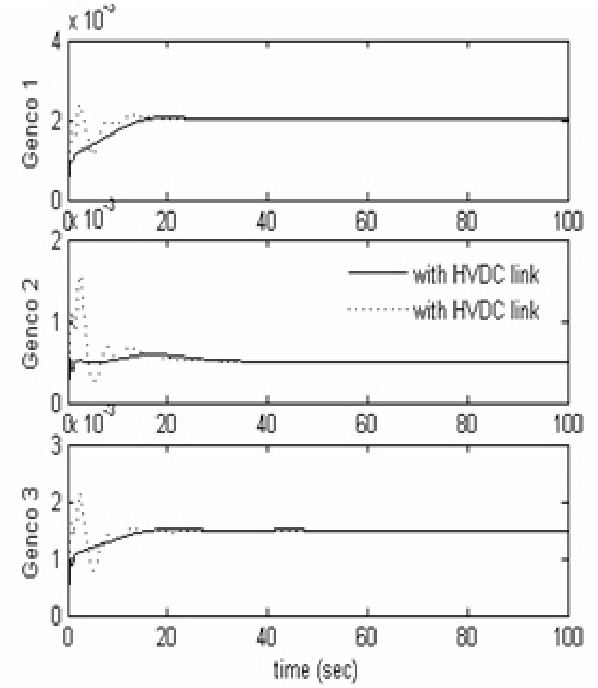

Fig. 5. Generation of Gencos in area 1

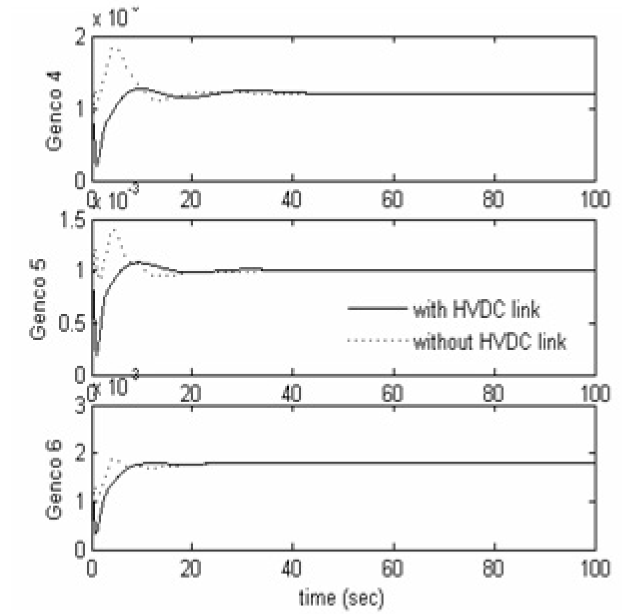

Fig. 6. Generation of Gencos in area 2

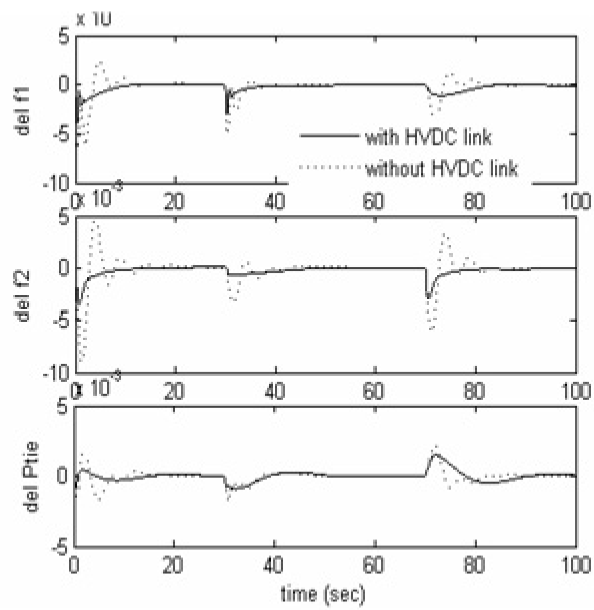

Fig. 7. Variations in area frequencies and tie-line power deviations during contract violation

EHVAC link can be expected to be utilized as a new ancillary service for stabilization of frequencies and tie power oscillations in the deregulated environment of power systems.

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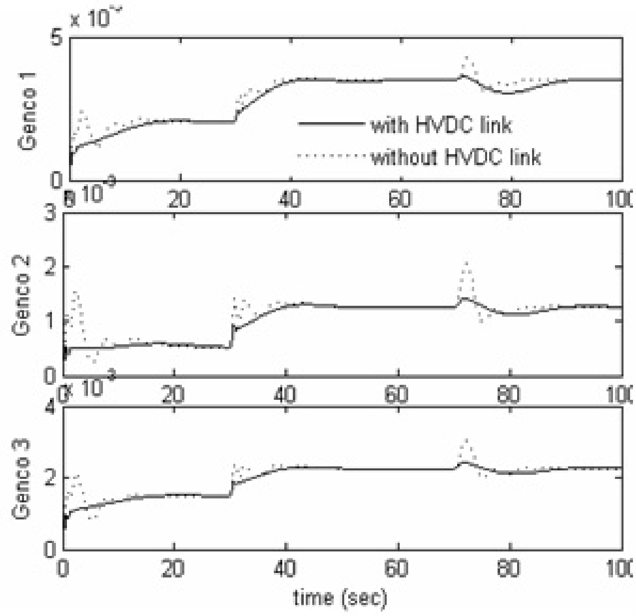

Fig. 8. Generation of Gencos in area 1 during contract violation

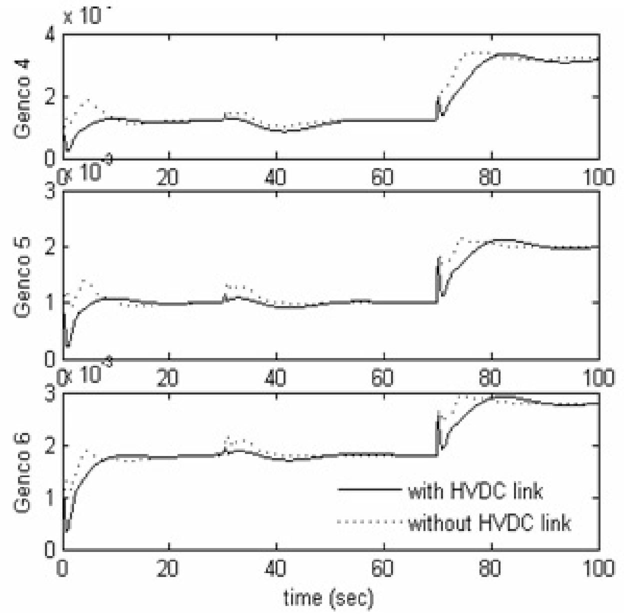

Fig. 9. Generation of Gencos in area 2 during contract violation

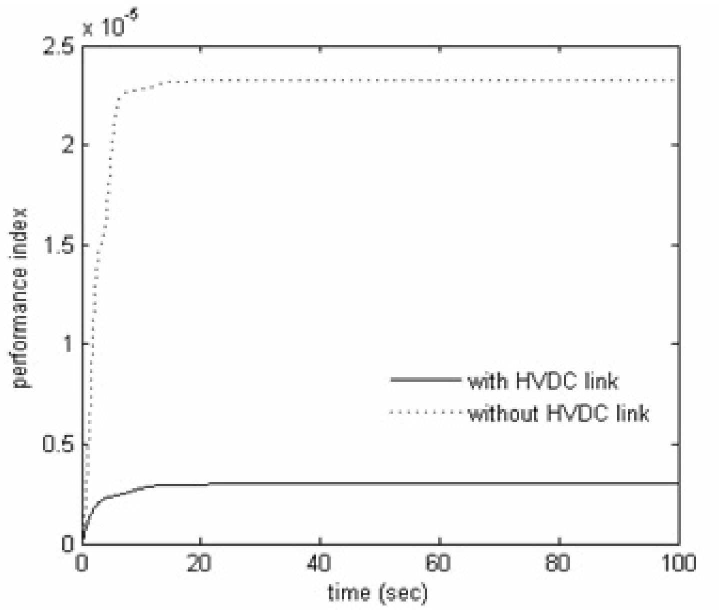

Fig. 10. Performance index values

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