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Comparative Study on Power Transmission Modeling in Large Scale AGC Power System

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Abstract. This paper presents a comparative analysis for various type of power transmission modeling in multi-area AGC power system. AC power transmission, parallel AC-AC transmission lines and parallel AC-DC transmission modeling in two-area LFC power system is presented and the results are compared. Based on simulation results the positive effects of HVDC links under random load disturbance are demonstrated.

Key words

Load frequency control, Power transmission modeling, Power system modeling and control.

1. Introduction

During the last decade, our power industry is faced up to major changes though deregulation and restructuring of conventional power system for providing high quality electrical energy in the competitive environment [1]. This new developments in the power system restructuring requires innovations in various parts, especially in the transmission networks, as its reliability plays a critical role in this new deregulated environment [2].

DC interconnections are one of the most interesting applications of power electronics in transmission systems. The future power-electronics based HVDC transmission system offers new aspects for the improvement of frequency control that can contribute to increase the efficiency and reliability of power systems [3-6].

The conventional A.C. transmission systems impose kind of limitation to transfer the power in the deregulated power system especially in the case of transmission between unsynchronized AC systems [7]. The AC transmission systems have various limitations such as: the Ferranti effect in long transmission lines, the capacitive effect of under ground cables, the influence of the line inductance and the issue of the stability of interconnected power systems [3-4]. In long transmission line based on HVAC cables, the problem of reactive power due to the HVAC cables charging is very important. In addition, the length of these cables limits the ability of active power transmission, which is decreased as the length of the line increases [7].

On the other hand, the HVDC transmission system has many advantages that can provide solutions to existing problems in the A.C. systems and thus increased the stability of the system [5-6]. VSC-HVDC systems provide better grid connection solution for weak grids and unsynchronized AC systems. Specifically, the VSC of the HVDC can work in both directions; it provides efficient voltage control with a better power flow controllability [8]. The requirements in the frequency control and net power interchange in a multi-area interconnected power system are settled by the Automatic Generation Control (AGC). Its concept is discussed and well known in [9]–[13].The main goal of the load frequency control (LFC) in a power system is to maintain the frequency of each area and tie-line power flow (in interconnected system) within specified tolerance, by adjusting the MW outputs of the generators to accommodate the fluctuating load demands [12-13].

In this paper, in order to improve the AGC system performance and avoiding HVAC limitations, particularly using for long distance transmission, a new supplementary modulation controller for a bi-directional VSC-HVDC system is proposed. Also a kind of comparative study for parallel AC-AC and AC-DC links is presented and the advantages of DC links are discussed.

2. AGC Power System Model

In this paper the study case of the power system to be analyzed is assumed to contain two areas, where two generation companies have been considered as shown in Fig. 1. Also, generic diagrams for tree case studies in two-area LFC system are shown in Fig. 2.

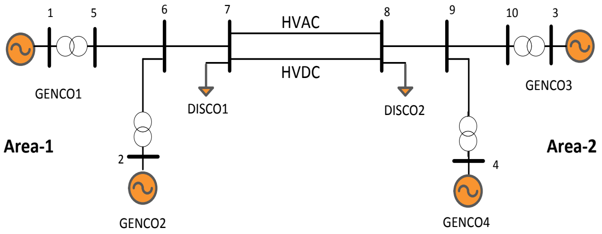


Fig. 1. Two-Area studied model

The equivalent model of this system can be represented in differential as:

$$ACE_1 = B_1 \Delta f_1 + \Delta P_{12} \quad (1)$$

$$ACE_2 = B_2 \Delta f_2 + \Delta P_{21} \quad (2)$$

Where P_{12} is the net tie-line power flow; $\Delta f = f_{actual} - f_{scheduled}$, and f is the system's frequency; B_i is referred to as the frequency bias and is generally referred to as the tie line bias control [14].

$$\Delta f_1 = \frac{K_{p1}}{1 + sT_{p1}} (\Delta P_{m1} + \Delta P_{m2} - \Delta P_{d1}) \quad (3)$$

$$\Delta f_2 = \frac{K_{p2}}{1 + sT_{p2}} (\Delta P_{m3} + \Delta P_{m4} - \Delta P_{d2}) \quad (4)$$

3. AC Power Transmission in AGC Model

Conventionally, the AC power flow on the transmission line from one area to another can be presented by:

$$P_{12} = \frac{E_1 E_2}{X_T} \sin(\delta_1 - \delta_2) \quad (5)$$

After linearization though operating points we have:

$$\Delta P_{12} = T \Delta \delta_{12} \quad (6)$$

$$T = \frac{E_1 E_2}{X_T} \cos(\delta_1^0 - \delta_2^0) \quad (7)$$

So we can model the behaviour of active power by changing of frequency between two area.

In case of parallel AC tie-lines, power flows in each line will be proportional to the inverse of the line impedance and by changing the impedance of each line we can change the participations of power flows though each line. In this type of parallel AC transmission there will be a lack of reliable control and power flows in accordance to line impedance that have no relation to contracts or desired amounts of power. So in this type of systems, applications of FACTs controllers will be necessary. Another solution especially for long distance interconnected systems is the transferring of power though HVDC lines or parallel AC-DC links.

4. Design of Power Modulation Controller for HVDC Link

A new designed bi-directional power modulation controller is proposed in this paper to control the power flow through the VSC-HVDC link in a two area power system.

By means of DC link in parallel with AC link, tie-line power will be included of DC and AC power like this:

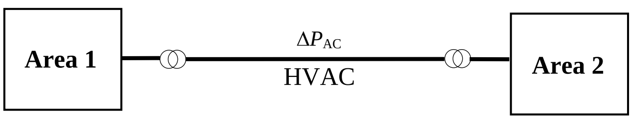
$$\Delta P_{12} = \Delta P_{DC} + \Delta P_{AC} \quad (8)$$

The DC link in this case, thanks to the use VSC-HVDC technology, act as a bi-directional line that includes two converter stations, one performing as a rectifier at the sending side, and the other performing as an inverter at the receiving end [5-6]. In the next part of this section, general information about the structure of the VSC-HVDC system implemented in this case is reviewed and finally the new design based on including a supplementary modulation controller for a bi-directional VSC-HVDC system in a multi-area power system is explained.

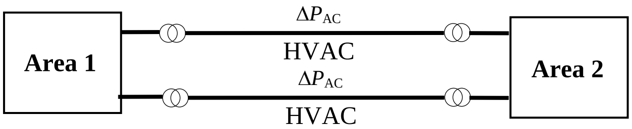
C. VSC-HVDC SYSTEM

A general configuration of the VSC-HVDC system is shown in Fig. 1. As depicted in the figure, it consists of four basic parts such as: dc-link capacitors, AC/DC and DC/AC converters, transformers and a dc cable.

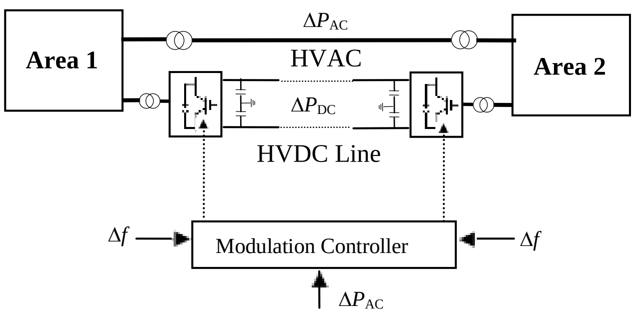
Industrial plants are connected to the VSC-HVDC system at a point of common coupling (PCC) [5]. The converters are VSCs which are normally build using insulated gate bipolar transistor (IGBT) power semiconductors, one operating as a rectifier and the other as an inverter. Depending on the application, two converters are connected either back-to-back or through a dc cable.



(a) Case1: HVAC



(b) Case2: Parallel AC/AC



(c) Case3: Parallel AC/DC

Fig. 2. Modified interconnected AGC system.

D. Controller design

If the frequency deviations are sensed, it can be used as a control signal to the HVDC unit to control the power flow as explained in [6] and [14]. In this paper, it is assumed that the VSC-HVDC is bi-directional and as a result the frequency in each area must be sensed. So the feedback scheme is constructed using two measurable signals, frequency deviations for each area and the power deviation in the AC tie-line transmission link. The proposed coordinated control strategy for this kind of HVDC link can be written as follows:

$$\Delta X_{DC} = K_{f1}.\Delta f_1 + K_{DC}.\Delta P_{AC} + K_{f2}.\Delta f_2 \qquad (9)$$

Where ΔX_{DC} is the control signal for the VSC-HVDC link, K_{f1}, K_{f2} and K_{DC} are control gains. The HVDC link is also represented in the form of a transfer function:

$$\Delta P_{DC} = \frac{1}{1+sT_{DC}}.\Delta X_{DC} \qquad (10)$$

where T_{DC} is the time constant of the HVDC unit. Thus the total tie-line power flow perturbation in AC-DC system becomes:

$$\Delta P_{12} = \Delta P_{DC} + \Delta P_{AC} \qquad (11)$$

$$\Delta P_{AC} = \frac{2\pi.T_{12}}{s}[\Delta f_1 - \Delta f_2] \qquad (12)$$

Where ΔP_{AC} is an AC tie-line power deviation, ΔP_{DC} is a power modulation by HVDC link and T_{12} is the tie-line synchronizing coefficient between areas [12].

5. Simulation Results

In this Section, in order to evaluate the effects of the power modulation controller of the VSC-HVDC link against load variations, simulations are performed for one scenario of possible operating conditions and large load demands. The results for AC-DC case are also compared with AC line and two parallel AC-AC lines.

Simulations are performed with MATLAB platform and the power system parameters are taken from [17].

In this case it is assumed that the load in area 1 is suddenly increased to 0.07 p.u.MW, at t=2s and all generators participate in LFC defined by the following apf:

$$apf_1 = 0.75 \quad , \quad apf_2 = 1 - apf_1 = 0.25$$

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

In case of parallel AC-AC system we also assumed the two AC lines are similar with a same inductance. Based on these conditions, simulation results for this case are presented in Figs. 3-6. The controller values for DC link obtained from the design of the power modulation controller are given in the Table I.

Table I. - Results of HVDC Control

K_{f1}	2.98
K_{f2}	4.10
K_{DC}	0.17

As shown in Figs. 3 and 4, dynamic responses of frequency in both areas are improved by using two parallel transmission lines

Also as shown in Figs. 5and 6, the magnitude of the first overshoot of tie-line power deviation is suppressed by the HVDC. This result clearly confirms the positive effects of HVDC link to increase the stability and also the capacity of transmission line between two areas.

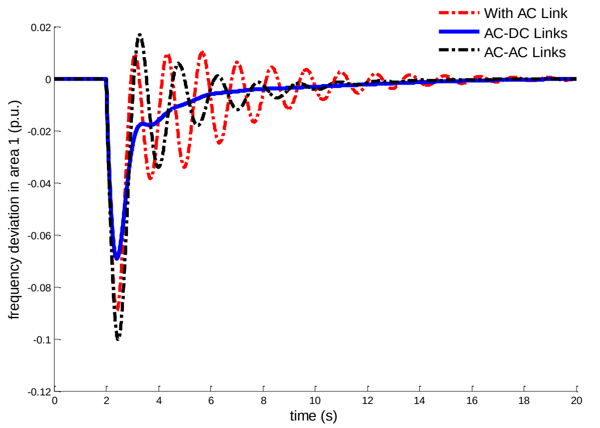


Fig. 3. Frequency deviation for 0.07 p.u. step load change in area 1.

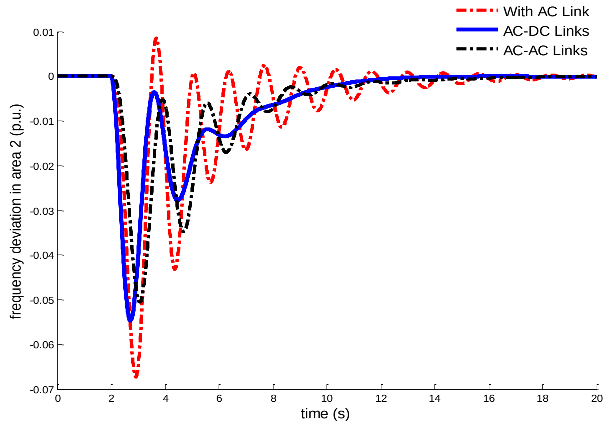


Fig. 4. Frequency deviation for 0.07 p.u. step load change in area 2.

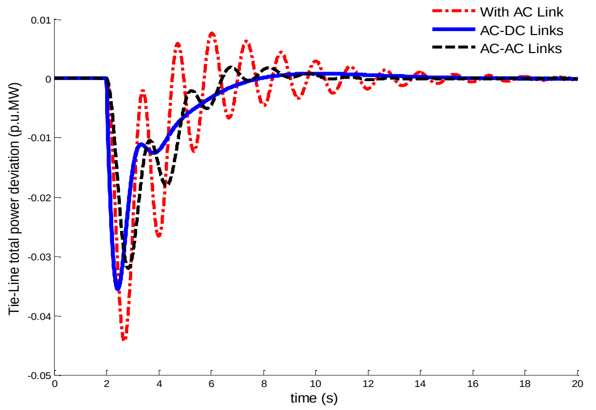


Fig. 5. Tie-line power flow deviation for 0.07 p.u. step load change.

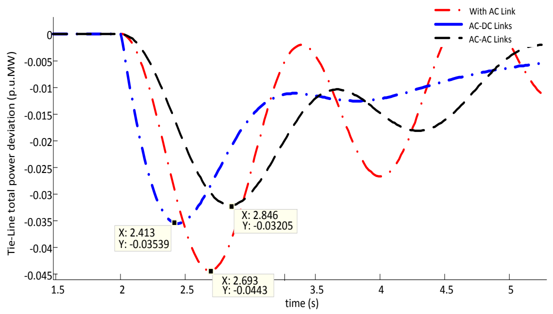


Fig. 6. First overshoot of power flow transiend for 0.07 p.u. step load.

4. Conclusion

In order to have a kind of comparative study for generic models of power transmission and to show the positive effects of HVDC links for random load disturbance, dynamic performance of a two-area interconnected power system with a bi-directional VSC-HVDC link is simulated. In this way, a new supplementary modulation controller for a bi-directional AC-DC transmission link is proposed. Based on the simulation results and comparisons between AC transmissions and AC-DC systems it has been stated that the use of HVDC transmission lines in parallel with HVAC transmission lines increases the strength and the stability of the system.

In HVDC transmission lines we will have complete control on the transmitted power while this type of control on AC link is not easy and usually in order to have more control and also avoiding stability problems, application of FACTS controllers in AC lines will be necessary. In order to increase the stability of the overall interconnected power system the trends should be more focused on decentralized controller. Because in the future modern power system with high penetration of DGs and power electronics part like stations of HVDC, the system will be more complex and in order to guaranty the high reliability of the system, individual control for each part is necessary.

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