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Paper 310 Cigré SC B4 2009 Bergen Colloquium

Damping Low Frequency Oscillation by HVDC Supplementary Control In an AC/DC Parallel Transmission Power System

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SUMMARY

The paper presents the study on low frequency oscillation (LFO) mitigation in an interconnected power system with AC/DC parallel transmission lines [1]. The Small Signal Stability Analysis software SSAP is developed for largescale power system LFO analysis. Eigen-analysis of linearized power system show that both inter-area modes and local modes of LFO exist (0.2Hz<frequency< 2.0Hz), furthermore, weak damping (e.g.damping ratio <0.05) make the power system operate under the potential of oscillation. Eigenvector of each mode shows the generators are divided into groups, which may oscillate against one another.
The types of division are different and each type related to one special oscillation mode.
Power System Stabilizer (PSS)s as traditional approach to mitigate LSO were already equipped in excitation systems of all the large capacity generators and show their effectiveness.
The paper studies how to apply the supplementary control of HVDC to further enhance the damping of inter-area modes and suppress LFO. Double-side AC frequency difference control for each HVDC is called the frequency difference modulation. Power flow and current in AC tie line and voltage at AC bus or their combination may be choosen as remote control sigals. Case study of coordinate control takes the summation of active power flow in 3 different AC tie lines acquired by Phase Measurement Unit System (PMU) as input signal for both sides of 3 HVDCs. Eigen-analysis shows the designated coordinate control is significantly effective to the critical oscillation modes.

KEYWORDS

HIGH VOLTAGE DIRECT CURRENT (HVDC) SYSTEMS, LOW FREQUENCY OSCILLATION (LFO), SUPPLEMENTARY CONTROL (SC), PHASE MEASUREMENT UNIT (PMU)

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I. INTRODUCTION

Along with the increment of scale and complexity of the interconnected power systems many transmission lines are more than thousand kero-meters long. Inter-area low frequency oscillation (LFO) becomes a bottleneck of power system operation. Small signal stability analysis software package SSAP is specially used for LFO analysis [2]. Low frequency oscillatory instability occurred all over the world during the past decades [3-6]. How to characterize and mitigate the oscillations effectively is an engineering problem in concern. The factors affecting the oscillation modes the most and the necessary measures to enhance overall system stability need intensive studies.

Power System Stabilizers (PSS) consisted in generator excitation systems are effective to mitigate LFO, especially for the local oscillation modes. They also supply damping of the inter-area oscillation in some extent [7]. PSS were installed on all the generators of large capacity now. Besides, the influence of HVDC supplementary control on LFO must be studied [8].

There are only a few AC/DC parallel transmission systems in the world. The analysis of this type of the interconnected systems is more sophisticated but the supplementary control of the HVDC system does help in enhancing small signal stability, especially for damping the inter-area modes. The study on the China Southern Power Grid show that the damping of critical oscillation modes are significantly improved by implementing the HVDC supplementary control [9,10].

I. POWER SYSTEM AND SOFTWARE COMPUTATION

China Southern Power Grid locates in a vast area of the southern most part of China, including five provinces: Guang Dong(GD), Guang Xi(GX), Gui Zhou(GZ), Yun Nan(YN) and Hainan(HN). It is also closely connected to Hong Kong(HK) city. The hydraulic power is distributed in the west and the load centers are concentrated in the east. AC/DC parallel transmission lines are interconnected in between, which diliver bulk power load usually at 10GW level.

A. 2007 System Description in Brief

The system model for analysis includes 247 generators, among which 35 equipped with PSS in IEEE type excitation system models; 1399 nodes; 2227 branches and 623 loads of ZIP static models. 4 HVDC links are represented by Quasi-Steady-State (QSS) models specially defined in SSAP.

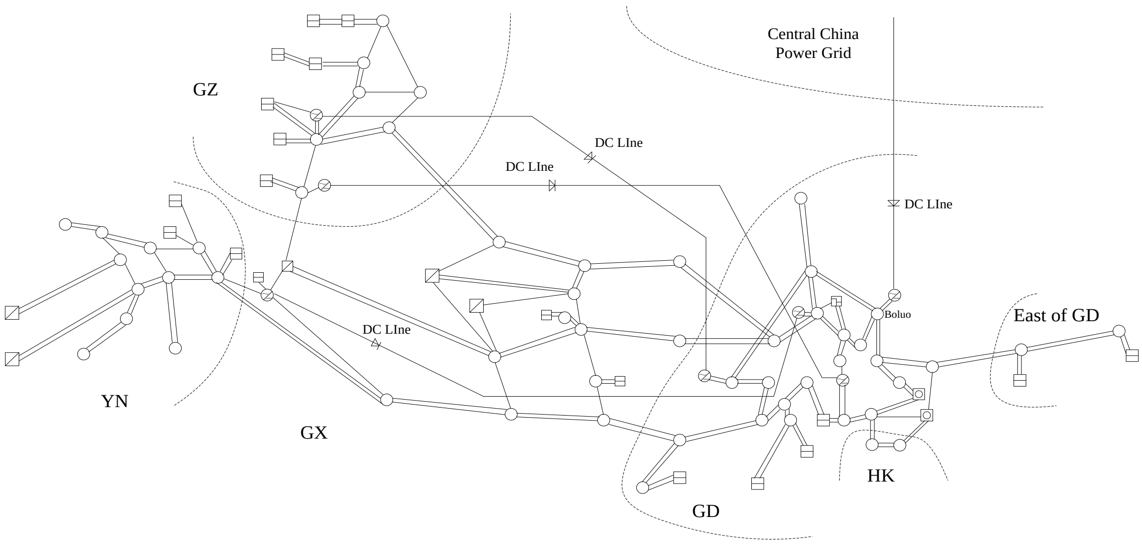

Fig.1. Transmission Line Diagram of 2007 system

In system simulation if 3-phase to ground fault (230kV line) starts at 0.8 sec and continues for 0.06 sec. The active power oscillation on a 525 kV tie line is shown in Fig.2.

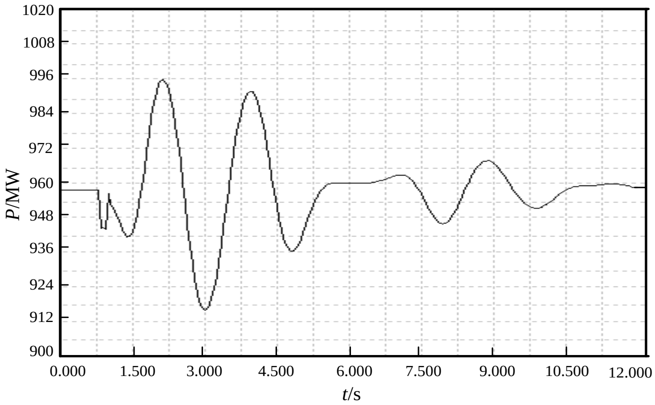

Fig.2. Active Power Oscillation after Disturbance

The inter-area LFO oscillation modes drawn by Prony identification are listed in Table 1. The data shedded are related to inter-area mode and considered in this paper.

TABLE 1
Inter – Area Oscillation Modes Identified

Amplitude MW	Initial Phase Angle °	Frequency Hz	Damping Ratio
957.39	0.00	0.00	1.000
33.29	-128.72	0.410	0.066
64.67	-121.74	0.603	0.082
5.31	-4.52	0.794	0.046

B. Small Signal Stability Analysis Software Package (SSAP)

The software package for small signal stability analysis, SSAP, was developed by Shanghai Jiao Tong University. The algorithms for eigen-analysis are Implicitly Restarted Arnoldi Method (IRA) and QR algorithm applying Gaussian Elimination (GE), respectively. IRA is specially for computing large scale power systems LFO and QR for limited scale power systems.The eigen-analysis result by IRA method in SSAP software package is listed in Table 2.

TABLE 2
Results of Eigen-Analysis by SSAP

Real part	Imaginary part	Frequency Hz	Damping ratio
-0.151	2.536	0.403	0.058
-0.369	3.676	0.585	0.100
-0.143	5.239	0.786	0.028

The inter-area mode 1 is 0.41 Hz with damping ratio 0.066 in time domain analysis and 0.403 Hz with damping ratio 0.058 in frequency domain analysis, both of which are approxitely the same.

Right eigenvectors of mode 1 related to generators are shown in Fig.3. It illustrates that GD, HK, GX and YN, HN all oscillate against GZ except a few generators inside GZ. Mode 1 is a typical inter-area oscillation mode among groups of large amount of generators.

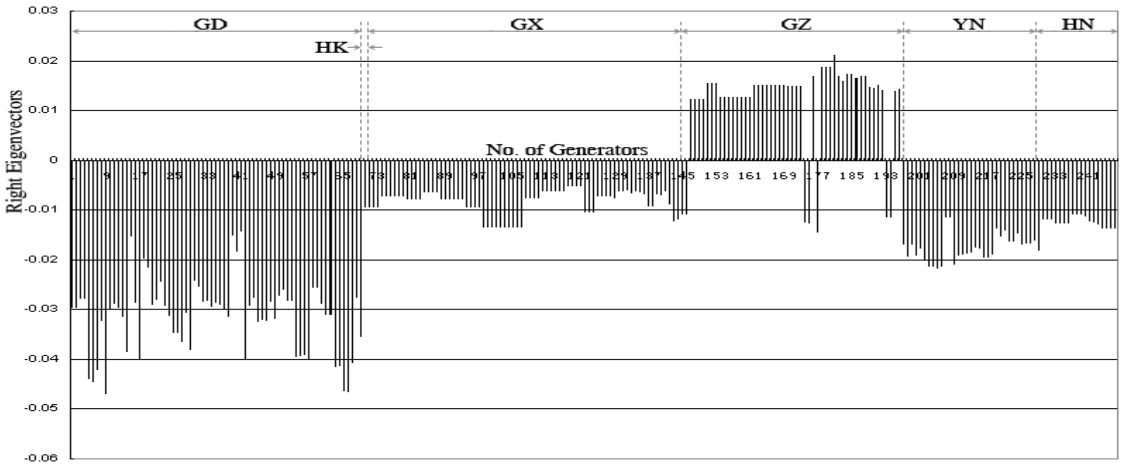

Fig.3. Generators in Groups Oscillate Against Each Other in Mode 1

The participation factor shows that several generators in GD, several generators in YN and some generators in GZ play important roles in oscillation mode 1, which is shown in Fig.4..

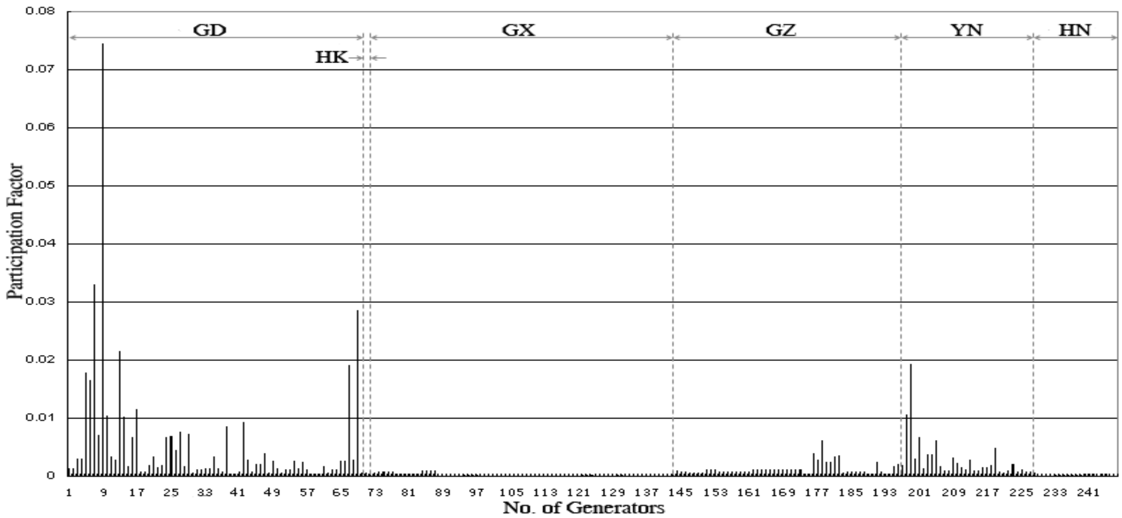

Fig.4. Participation Factor of Generators in Mode 1

II. HVDC MODULATION AND LFO SUPPRESSION

HVDC modulation is implemented by the supplementary control with the input signals, e.g. frequency, power, voltage etc. from the AC busses. It was first applied at the Pacific Tie Line AC/DC parallel transmission in 1976.

In the system studied in the paper damping of the first oscillation mode 0.410 Hz is weak. The generators related to the mode are already equipped with PSS to enhance the damping.

Mode 1 is the oscillation between the west (GZ) and the east (GD,GX, and YN,etc.). The generators with significant participation factors are distributed at both sides of the HVDC line from GZ to GD which is there-after selected for implementation of supplementary control. The input signals are tried one by one.

At the terminal of rectify side the active power deviation of the AC line parallel to the HVDC is selected to be the input signal. The block diagram of the supplementary control is shown in Fig.5.

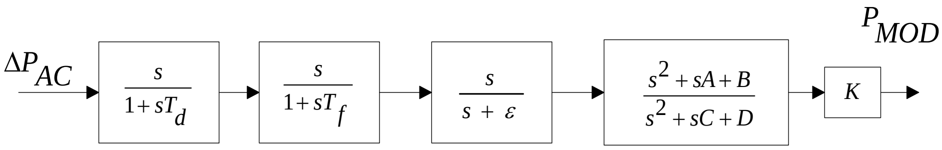

Fig.5. HVDC Supplementary Power Modulation Control

Where $T_d = 10$; $T_f = 0.15$; $\varepsilon = 1$; $K = 3$; $A = B = C = D = 0.1$

TABLE 3

Eigenvalues of System with GZ-GD HVDC Power Modulation

Real part	Imaginary part	Frequency Hz	Damping Ratio
-0.180	2.538	0.403	0.071
-0.373	3.691	0.587	0.101
-0.142	4.938	0.786	0.029

Table 3 shows that the damping of mode 1 increases from 0.058 to 0.071 due to the power modulation..

Then, at the terminal of inversion side the extinction angle γ is selected to be the input signal for the supplementary control of the inversion bridge. The block diagram of γ angle modulation is shown in Fig.6.

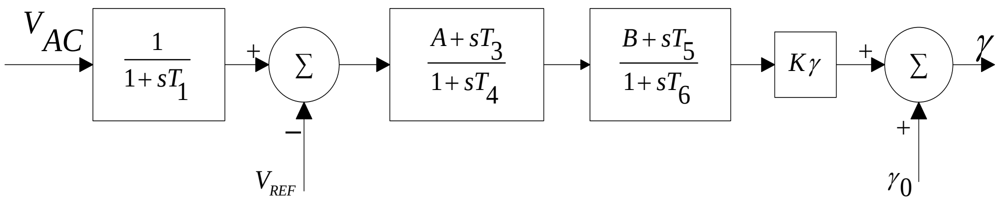

Fig.6. HVDC Supplementary γ Modulation Control

Where $T_1 = 0.1$; $T_3 = T_4 = T_5 = T_6 = 0.1$; $K_\gamma = 2$; $A = B = 0$

The results in Table 4 show that the damping of Mode 1 further increases from 0.071 to 0.140, therefore, inter-area mode 1 is well damped by supplementary control of HVDC.

TABLE 4

Eigenvalues of System with γ Modulation Control

Real part	Imaginary part	Frequency Hz	Damping Ratio
-0.379	2.679	0.426	0.140
-0.364	3.797	0.604	0.096
-0.143	4.928	0.784	0.029

However, in these two cases mentioned above the damping of mode 3 does not change no matter what kind of signals input to supplementary control. Anyway, it still could be improved by PSSs, however, it is out of the scope of this paper..

III. COORDINATE CONTROL WITH REMOTE AC INPUT

A. Description of 2012 System in Planning

In the year of 2012 a ± 800 kV HVDC transmission line from the west (YN) to the east (GD) will be put into operation as the backbone between YN to GD. The AC/DC transmission system is modeled in more detail with 536 generators (529 modeled in d q axis and Park's

Equation, 7 in classical model with E' constant), in which 494 with excitation models and 140 equipped with PSS; 2657 nodes; 4034 lines and 930 loads in ZIP static load models. The system infrastructure will be enhanced as Fig.7.

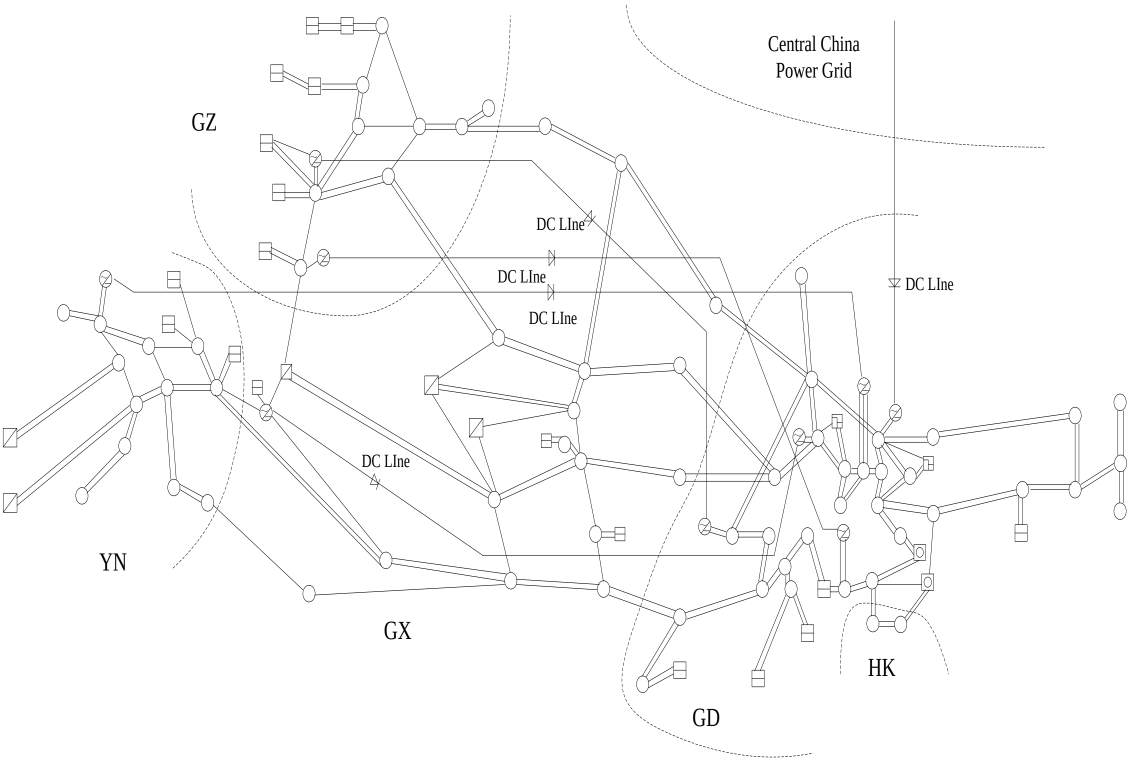

Fig.7. Transmission Line Diagram of 2012 System

B. Designation of HVDC Modulation in 2012

1) Damping Improved by Frequency Difference Modulation

The modulation input signal ω_1 and ω_2 are taken from HVDC YN side and GD side AC busses, respectively. 2 signals acquired on sites are conducted by optical fibres, the summation of which is to be the input of the rectifying converter and the inverting converter, respectively, also thousands of miles away.

The block diagram of supplementary control of one side is as Fig.8.

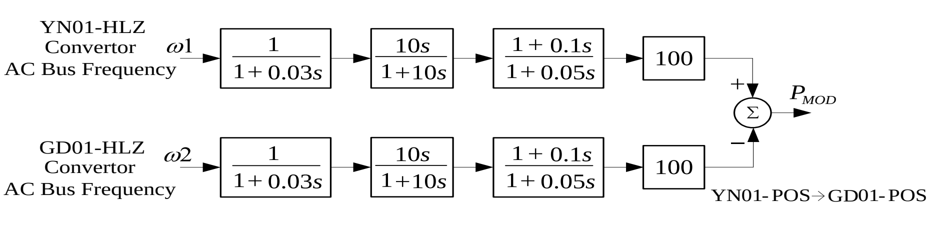

Fig.8. ±800kV HVDC Supplementary Control Block Diagram

The eigen-analysis shows that the critical mode is the oscillation between two groups of the generators, i.e. GD and HK versus YN, GZ, and GX.

The HVDC modulation by frequency difference from both-sides improves damping of the critical mode.

TABLE 5
Critical Eigenvalue Mode 1
Damping Improved by Frequency Difference Modulation

	Real part	Imag. part	Freq. Hz	Damping ratio
before	-0.1652	2.8629	0.4556	0.0576
after	-0.1832	2.8602	0.4552	**0.0639**

Damping Improved by Remote Control

The HVDC modulation with input signals of AC/DC power transmission from distance, e.g. the summation of AC power from 3 AC tie lines in YN as input to the supplementary control of the both sides of the backbone HVDC may improve another mode, i.e. mode 2 at the same time.

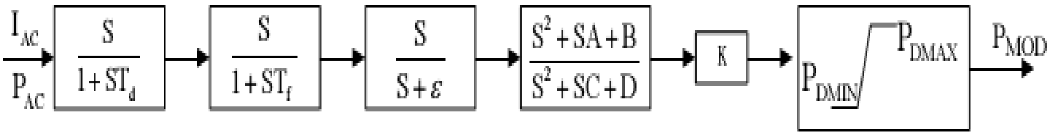

Fig.9. The Block Diagram of Line Power from Distance As modulation input signal

TABLE 6
Critical Eigenvalue Mode 2
Damping Improved by Frequency Modulation

	Real part	Imag. part	Freq. Hz	Damping ratio
before	-0.1255	3.8499	0.6127	0.0326
after	-0.1568	4.1403	0.6589	**0.0378**

Damping Improved by Coordinate Control

If the supplementary control of 3 designated HVDC transmission lines all take the summation of 3 remote AC power flows by Phase Measurement Unit (PMU) as input signal the damping improvement of mode 1 is significant while the frequency of low frequency oscillation decreses. Besides, the damping of mode 2 and 5 also be improved in some extent. Table 7 shows the comparison of mode damping with and without coordinate control .

TABLE 7
Mode Damping with or without Coordinate Control

	Without coordinate control		With coordinate control	
	Frequency Hz	Damping ratio	Frequency Hz	Damping ratio
Mode 1	0.4550	0.0635	0.2897	0.1720
Mode 2	0.6017	0.0546	0.6419	0.0633
Mode 5	0.8527	0.0492	0.8765	0.0599

IV. CONCLUSION

The China Southern Power Grid is an AC/DC parallel transmission interconnected power system which is operated with the potential of low frequency oscillation. All the large capacity generators are equipped with Power System Stabilizer (PSS). For such complicated power system structure HVDC supplementary control is designated to be the approach to enhance the damping of low frequency oscillation, especially for the inter-area oscillation modes. Eigen-analysis by SSAP software shows the modulation effects of different input signals which includes frequency difference of HVDC both-side AC busses, power deviation of AC buses, extinguishing angle γ, etc. Furthermore, active power or current from remote AC tie lines and voltage of AC busses acquired by PMU system on sites could also be the input signals of supplementary control of HVDC, so called coordinate control, is also shown to be effective.

BIBLIOGRAPHY

[1] M.Szechtman, W.f.Long, et.al, The Role of SC B4 – HVDC and Power Electronics in Developing the power Grid for the future (Electra number 238, July 2008)

[2] Hanyu Gu and Chen Chen, "Using Implicitly Restarted Arnoldi Method for eigenanalysis of power systems” IFAC’99 IFAC World Congress, Proceedings IFAC-7C-05-1, July 5-9, 1999.

[3] F.R. Schlief, J.H. White, "Damping for the northwest-southwest tie line oscillations-an analog study,” IEEE Trans. Power Apparatus and Systems, vol.85, No.12, pp.1239-1247, Dec. 1966.

[4] D.K. Kosterev, C. Taylor, W.A. Mittelstadt, “Model validation for the August 10, 1996 WSCC system outage,” IEEE Trans. on Power Systems, vol. 14(3), pp.967-979, 1999.

[5] D.K. Kosterev, W.A. Mittelstadt, M. Viles, et al. “Modal validation and analysis of WSCC system oscillations following Alberta separation on August 4, 2000,” Final Report by Bonneville Power Administration and BC Hydro, 2001.

[6] G.J. Lou, X.H. Xu, S.Q. Long, Q.C. “Low frequency oscillation on the interconnector between Hong Kong and Guagndong,” Proc. of the Chinese Society of Electrical Engineering, Vol.6, pp. 29-35,Jan, 1988.

[7] A.R. Messina, J.M. Ramirez, C.J.M. Canedo, “An investigation on the use of power system stabilizers for damping inter-area oscillations in longitudinal power systems,” IEEE Trans. Power Systems, vol.13 (2) pp.552-559, 1998.

[8] T. Smed, G.Andersson, “Utilizing HVDC to damp power oscillations,” IEEE Trans. Power Delivery, vol 8(2), pp.620-627,1993.

[9] Fan Yang, “ HVDC modeling in AC/DC transmission systems and the supplementary damping study," Doctor dissertation, Dept. of Electrical Engeering, Shanghai Jiao Tong University, 2008.

[10] Liang Shen, “Small signal stability analysis software package SSAP and its application in AC/DC parallel transmission systems" Master thesis, Dept. of Electrical Engeerning, Shanghai Jiao Tong University, 2008.