Stability Improvement for Central China System

Kjell-Erik Högberg, Marie Ericsson, Abhay Kumar, Kerstin Lindén and Wen Weibing.

Abstract--**The stability study has been performed investigating the conditions for operation of the Three Gorges - Changzhou ±500 kV DC Transmission System. The systems involved in the study were the Central China and East China Systems interconnected with Three Gorges - Changzhou HVDC link and the existing Gezhouba-Shanghai HVDC system.**

Time simulations, frequency scanning and eigenvalue analysis have been applied for a thorough investigation of the possible means of enhancing system stability. Small signal stability (small disturbances) and transient stability (large disturbances) have thus been investigated. The basic resonance patterns with respect of damping properties were identified as well as some local causes of stability distortions.

The study shows, that in view of its location, the introduction of the damping controller in the Three Gorges - Changzhou HVDC link has very limited ability for damping the inter-area oscillations. The study has however shown that one effective mean to improve the damping in Central China System is to introduce the damping control by Power System Stabilizers (PSS) at local generators.

Index Terms--**Stability, Eigenvalue, Power modulation, HVDC, Oscillation, Damping, Stabilizer, PSS.**

I. INTRODUCTION

The purpose of the stability improvement investigation has been to define strategies for operation of the Three Gorges – Changzhou ±500 kV DC Transmission System (3GC) and determine whether stability can be improved by adding a damping controller based on HVDC power modulation. The ability to enhance power system stability based on HVDC power modulation depends on several factors including the location of the HVDC link converters, the feedback signal used as input to the control, as well as the internal characteristics of the AC system(s).

The 3GC transmission is a bipolar HVDC transmission basically designed to transmit 3000 MW rated power from Three Gorges Hydro Power Station to the East China area. The transmission can also operate in reverse power direction. Longquan converter station (located about 50 km from Three Gorges dam) will normally be operated as rectifier whereas Zhengping converter station (located in the city of Changzhou and about 200 km from Shanghai) as inverter.

The systems concerned in the study, consist of the Central China and East China Systems asynchronously combined with 3GC HVDC link (Fig. 1) and the existing Gezhouba-Shanghai (GeSha) HVDC system and to some extent the future Three Gorges - Shanghai (3GS) HVDC link (2010). The Sichuan System (in the province to the west) will also be connected to the Central China System synchronously.

The Three Gorges (3G) Hydro Power station (with 14 units of 700 MW in the Left Bank section and later further 12 units of 700 MW in the Right Bank) will be major components in the Central China System.

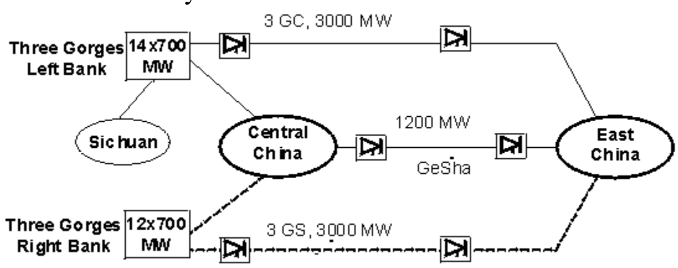

Fig. 1. Simplified system configuration

While investigating the influence of the 3GC HVDC link on the interconnected system dynamics, it has proved necessary to look into the involved AC systems to find out about their internal characteristics.Input data

The input AC network data was originally in the BPA format and has been converted to SIMPOW® format and validated for static and dynamic conditions, including system transient behavior.

The load modeling has been partly constant impedance, partly constant current and partly constant power (ZIP models) with various fractions for different regions, as stated in the original BPA input data.

II. FAULT CASE SCANNING

A. Case Descriptions

A large number of fault cases for 8 selected load flow cases, covering development stages from year 2003 to 2010 and seasonal load conditions, have been considered for the investigation for different levels of DC transmission power transfer. The fault cases included AC system faults with single-phase, phase-to-phase as well as three-phase faults. Some of these faults are quite severe faults with respect of initiation of oscillations and may in some cases cause transient instability.

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Also generator trip cases, due to internal reasons (no fault trip), have been investigated. For some fault cases the Central China System splits into two systems which causes power unbalance and substantial frequency deviations (though outside the scope of this investigation).

At DC line faults, the consequences of the power loss at a single pole fault in a bipolar transmission is reduced by increasing the power transfer in the healthy pole, at least temporarily.

B. Observations

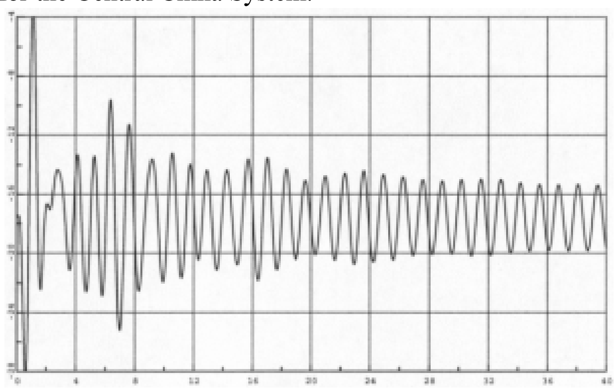
These investigations have given valuable information about the basic characteristics of the involved systems and knowledge of its dynamic behavior was established. The basic resonance patterns with respect of frequencies and damping properties were identified as well as some local causes of stability distortions.

The observations with respect to oscillating frequencies and damping properties are used for comparisons with the small signal analysis results as described below.

1) Central China System

The Central China System consists of several long radial connections (of which the Sichuan connection is the dominating) from a compact center. Unfortunately only a few of the generators (in the Sichuan System and 3G) are provided with power system stabilizers (PSS). The combination of this condition and the radial structure is likely the cause of poorly damped oscillations as experienced in the fault case scanning.

The experience of a typical fault case scenario with respect to poor damping is illustrated in the plot of a generator rotor angle oscillations in Fig. 2, which shows the oscillation pattern for the Central China System.



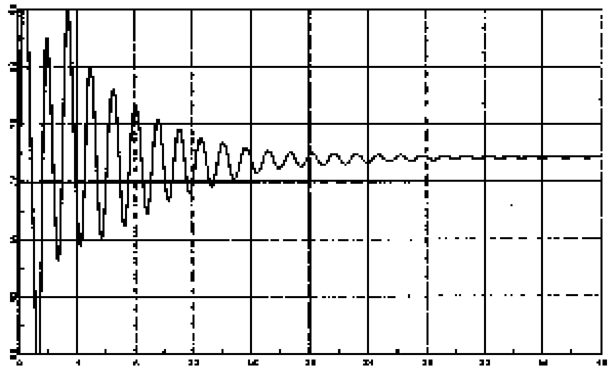
Time seconds

Fig. 2. Rotor angle of a typical Central China System generator, following an AC system fault.

2) East China System

The East China System is more compact (meshed) and better damped than the Central China System, in spite of the fact that no generators are provided with damping controller (PSS) and that some generator groups are connected via radial lines.

The experience of a typical fault case scenario with respect to damping is illustrated in the plot of a generator rotor angle oscillations in Fig. 3, which shows the oscillation pattern for the East China System.



Time seconds

Fig. 3. Rotor angle of a typical East China System generator, following an AC system fault.

3) Common Features

It is seen that a fault causes a local disturbance, which is usually damped out reasonably fast, but also initiates a disturbance that influences the complete system and has a characteristic common for most faults.

It is found that the same pattern of oscillations, appeared in most of these cases and that the fault condition in itself usually was of less importance. The characteristic of the post fault system is however of importance at severe disturbances.

4) Interconnected Systems

When the two asynchronous systems are interconnected with HVDC links, the attempt to damp oscillations caused by a disturbance in one system with the assistance of the other, may cause the oscillations to be transferred also to the other. This is the result of the principle based on the intention to damp oscillation in one system by taking energy from the other.

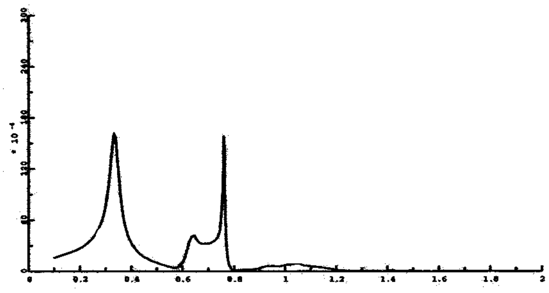
Central China System is less stable in cases with normal power direction compared to cases with reversed power direction. The opposite goes for East China System, which is less stable in cases with reversed power direction compared to cases with normal power direction.

III. Small Signal Stability

A. Frequency Scanning

The initial investigations of small signal stability characteristic were carried out by frequency scanning of the systems in the range from 0.1 Hz up to 2 Hz. Individual systems as well as interconnected systems were investigated. The frequency response due to a perturbation in the mechanical torque of some selected machines as input and the machine speed deviation as output signal was recorded for some machines and an example is shown in Fig. 4.

The dominating resonance peaks at 0.38 and 0.76 Hz can be observed in Fig. 4. These resonance peaks that match with observations are discussed in the section below. It is obvious that the damping of the narrow peak at 0.76 Hz is low, while the peak at 0.38 Hz is better damped. Some indication of a local resonance is also shown at 0.65 Hz in the plot.



Frequency Hz

Fig. 4. Frequency scanning of rotor angle of a Central China System generator

The amplitudes of the peaks depend on the electrical distance between the perturbing and observed generators.

Perturbing with DC power modulation was also tested but due to reasons as described in section V. B. 3) below, the response was insignificant.

B. Eigenvalue Analysis

Eigenvalue analysis of the systems was performed in post fault conditions to study the location of eigenvalues for load flow cases with poor damping conditions.

The Central China and East China Systems were first studied separately without the HVDC dynamics. In each case the DC power export and import was represented as constant impedance loads (positive and negative respectively). Later the interconnected systems were studied and comparisons were done.

1) Central China System

Two dominant eigenvalues were identified for the Central China System, close to the frequencies 0.38 Hz and 0.76 Hz. These are typical inter-area (i.e. between different areas within the same AC system) oscillation modes and apply for some of the year 2003 cases. For cases in the years 2005 and 2010 the frequencies decrease slightly, as the size of the system increases.

Of these modes, the one with 0.76 Hz is very poorly damped and is dominating the small signal stability. This oscillation mode can be seen in the sustained oscillations in Fig. 2 and narrow peak in Fig. 4.

The oscillation mode of 0.38 Hz is related to the connection to the Sichuan area and can also be identified in Fig. 2 and 4. This is however better damped.

2) East China System

For the East China System, eigenvalues with frequencies close to 0.56 Hz and 0.76 Hz were found. Also for the East China System, these frequencies apply for year 2003 cases and decrease slightly for cases in the years 2005 and 2010. They are both well damped as shown in Fig. 3.

3) Interconnected Systems

Oscillations in the Central China System excite modes in the East China System, due to the fact that oscillations propagate through the HVDC link. For the interconnected systems, the poorly damped eigenvalue at 0.76 Hz in the Central China System dominates the small signal performance.

The eigenvalues at 0.38 Hz and 0.76 Hz, as pointed out above, (which were found when the Central China System was analyzed separately) appear also in the interconnected systems.

A poorly damped mode thus exists around 0.76 Hz. This mode is associated with the dynamics of the Central China System. The Central China System is strongly influenced by faults in both the systems.

IV. Enhancing Small Signal Stability

A. Principles

The findings in the previous sections have shown that the system(s) have poorly damped inter area oscillations. These oscillations are basically associated with the dynamics of the Central China System. This section presents results from the investigation of ways to mitigate these low frequency oscillations.

1) Parallel AC Ties

For a system with parallel connection of AC ties with an HVDC link, oscillations on the AC ties can be damped by modulation of the active power of the HVDC link. This is the traditional way of using HVDC links for system damping improvement by HVDC power modulation. Examples of such HVDC projects are Rihand – Delhi and Chandrapur – Padghe projects in India.

2) Asynchronous Systems

For systems, which are operated asynchronously to each other and connected with an HVDC link feeding power from one system into the other system, which is the case for 3GC HVDC system, the conditions are different.

In general, inter-area oscillations do not exist between systems asynchronously connected to each other by an HVDC link. However, low frequency oscillations within one system may propagate through the HVDC link to the other system. This type of interaction becomes evident when the sending system is poorly damped.

If any of the systems contain groups of machines oscillating against each other, HVDC power modulation may be used to damp oscillations on the AC transmission line interconnecting these groups of machines. However, such possibility depends on the relative location of the HVDC converter terminals to the inertia of the machines in the two areas [1].

B. HVDC Damping Controller

1) Observability

In order to design a power modulator, which could help damping oscillations, an input signal needs to be fed into the controller. The oscillation mode to be damped needs to be well observable in the input signal [2].

In general, poor observability of such signal, to be used in a control system, leads to a low magnitude (low residue) of the transfer function, which means a low sensitivity. To be able to use this signal, it requires high feedback gain to increase damping (shift modes).

2) Signals

For purpose of this study, use of local variables as feedback signal is envisaged. Though global signals contain more information about the mode of oscillations and may be more effective to use for damping. However, it is important to note that the ability to control an unstable mode and to improve the stability, requires good observability also for a global signal. Global signals are also not readily available at the required location.

The machines in the Central China System which participate in the inter area oscillations are electrically far away from the converter station. The dominating 3G (SanXia) machines close to the 3GC HVDC converters do not participate to a very large extent to the inter-area mode of oscillations.

Frequency response of local signals (such as bus frequency), shows a very low magnitude of the transfer function around the critical frequency, which indicates a low observability.

3) Controllability

The controllability of a low frequency oscillatory mode by using HVDC power modulation is determined by the location of the HVDC converters (i.e. input node of modulated power) with respect to the oscillation pattern. This is described in [1].

In the case of the studied AC/DC system configuration, this property is related to the distant location of the converter terminals relative to the oscillating machines.

4) Consequences

The consequence of this low observability and low controllability of the oscillations makes it difficult to improve the poorly damped modes in the Central China System based on DC power modulation in 3GC HVDC link.

In this aspect it can also be mentioned that the converter controls of the existing interconnecting HVDC link, GeSha, do not include any damping control.

C. Power System Stabilizers

In addition to the investigation above, it was analyzed further to see if there could be other suitable methods to improve the AC system's performance.

A commonly used method to damp inter-area oscillations is to distribute the action of damping controllers by installing PSS units on major generators. As mentioned earlier, only a few of the units in the Central China System are equipped with PSS and none in the East China System.

Identification of suitable locations for placing PSS as well as tuning them for damping inter-area oscillations was outside the scope of this study. However, based on simulation results from the study, a simple procedure was used to demonstrate whether PSS could improve the damping of the system.

A natural choice as input signal is the machine speed deviation. PSS based on this signal was thus simulated in most of the machines in the North-Eastern part of the Central China System (the He Nan area). The used PSS circuit was simple and not tuned to optimal function and consisted only of static gain as the intention was only to prove the effectiveness of PSS.

The outstanding improvement of the damping of the system with the PSS feature included can be seen in Fig. 5, which shall be compared with the poor performance without PSS in Fig. 2 (with the same conditions and scales).

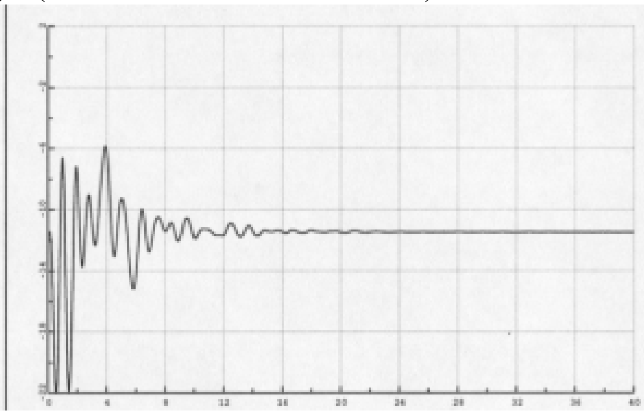


Fig. 5. Rotor angle of a typical Central China System generator (as per Fig. 2) following an AC system fault, with PSS introduced in He Nan area

V. CONCLUSIONS

The study results show that the East China System is a compact system and thus well damped, whereas the Central China System is poorly damped due to its configuration with long radial lines.

Time simulations, frequency response and eigenvalue analysis of specified fault cases have been applied to a thorough investigation of the possible means of enhancing system stability.

It has been shown that, owing to its location, the introduction of damping controller in the 3GC HVDC link is not effective in improving the damping in the Central China System, and that a robust mean to improve damping could be to introduce damping control (PSS) at local generators.

VI. ACKNOWLEDGMENT

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VII. REFERENCES

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VIII. BIOGRAPHIES

Kjell-Erik Högberg was born in Sweden 1940 and received his Master's degree at Chalmers University of Technology 1964 and then joined ASEA generating department. Since 1975 he has been active within ASEA/ABB with HVDC valve design, insulation coordination and system simulation.

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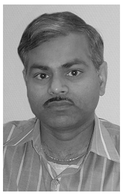

Abhay Kumar was born in Delhi, India in 1961. He obtained his degree in Electrical Engineering from University of Roorkee (now IIT) in 1982. He joined National Thermal Power Corporation Ltd. (NTPC) in 1982 and worked until 1995 as Deputy Chief Design Engineer for design of Vindhyachal B2B HVDC and Rihand - Delhi HVDC Projects and many other EHV substations. From 1995 to 2000 he worked for ABB Ltd. New Delhi as Senior Manager at Power System Engineering and Business Development department. Since May 2000, he has been working for ABB Power Systems AB as the Technical Manager for The Three Gorges - Changzhou ±500 kV DC Transmission Project.

Kerstin Lindén was born in 1963 and received her MS degree in electrical engineering and Lic. Eng degree in electric power systems from Chalmers University of Technology in 1988 and 1992, respectively. She is today technical manager at ABB T&D University, Sweden, planning and teaching courses in power systems, and system engineer at ABB Power Systems, working with system simulation. Previously, she was research manager for Power System Research at STRI, dealing with power quality, insulation co-ordination and reliability studies and university lecturer at Mälardalen University, teaching undergraduate courses in power systems.

Wen Weibing was born in Hubei, China in 1965. He obtained his Master's degree in Electrical Engineering from Chongqing University. During 1992-1995 he has been actively working for TSQ-GBJ HVDC Transmission Project. Since 1995 he has been working as Chief Design Engineer for Three Gorges – Changzhou ±500 kV DC Transmission Project.