Converter Station Design of the ±800 kV UHVDC Project Yunnan-Guangdong

Donghui Zhang[#1], Marcus Haeusler[#2], Hong Rao[*3], Chun Shang[*4], Tao Shang[*4]

[#] *Siemens AG, Energy Sector, Power Transmission Solution*
91056 Erlangen, Germany
[1]donghui.zhang@siemens.com
[2]marcus.haeusler@siemens.com

[*] *China Southern Power Grid Co., LTD.*
Guangzhou, China
[3]raohong@csg.cn
[4]shangchun@csg.cn
[5]shangtao@csg.cn

***Abstract*— As one of the most important power transmission schemes in South China the Yunnan-Guangdong ±800 kV UHVDC Project is currently under construction. This UHVDC link will connect Chuxiong in the Yunnan province to Suidong in the Guangdong province over a distance of 1418 kilometers. The significant increase of existing dc power transfer capability to its nominal bipolar dc power of 5000 MW is achieved by entering the ultra high dc voltage (UHVDC) operation range at a voltage level of 800 kV. Hence, it will be the dc transmission scheme with the world's highest dc operation voltage and presents a major step forward in HVDC technology.**

In this paper the basic design aspects of the overall converter station concept of the Yunnan-Guangdong ±800 kV UHVDC Project are introduced. Some highlights of main equipment taking into account challenges of the increased steady state and transient voltage stresses are given.

Keywords: UHVDC, Low SCR, Insulation Coordination

I. Introduction

In China, several giant hydropower plants are being constructed in the Southwest area, where the abundant hydropower resources will be exploited in the next three decades. As one of the most effective methods to reduce the greenhouse gas emission, such continuously generated clean energy will be transmitted to the gigantic urban areas in Eastern and Southern China through a large transmission distance in the range of 1500 to 2100 km.

As a result, HVDC long distance transmission schemes with a transmission capability of over 5000 MW has been determined as the most economic power transmission solution. In order to fulfil these demands, the maximum dc voltage levels of 500 kV to 600 kV in the currently world-wide existing HVDC schemes were determined to be increased to a new adequate level – 800 kV.

The world's first HVDC project in the Ultra High Voltage (UHV) range with an operation dc voltage of ±800 kV and a transmission capacity of 5000 MW – Yunnan-Guangdong UHVDC Project is now being constructed in China Southern Power Grid. The key features of this link and some design aspects for key UHVDC equipment were provided in [1]. This paper discusses the technical challenges from increased voltage and power rating to the ±800 kV UHVDC system and the special design requirements of the Yunnan-Guangdong UHVDC project. Some aspects of determination of converter station arrangement and design of equipments configurations and parameters are also provided in this paper.

II. General Information

A. Location

The Yunnan-Guangdong ±800 kV UHVDC project was designed to transmit 5000 MW dc power over a long distance of 1418 km from Chuxiong in Yunnan province to the load centre in Guangdong province. The rated dc current of this UHVDC link was determined as 3125 A, which is a little higher than that of 3000 A in the existing ±500 kV HVDC systems in China Southern Power Grid.

The Chuxiong Converter Station is located in Chuxiong City and about 58 km north-west to Kunming, where is high altitude area. The altitude of Chuxiong Station above China Yellow Sea level is 1850 m. The Suidong Converter Station is located at Zengcheng City in Guangdong Province, about 35 km away from Guangzhou and 16 km away from Zengcheng City. Though the altitude of Suidong Converter Station is very low, the industry centre around Guangzhou city is the heavy pollution area. Both high altitude and heavy pollution level are challenges for external insulation of the 800 kV outdoor equipments.

B. AC System Conditions

The Chuxiong Converter Station, which operates as rectifier in the normal power transmission direction, would be fed by two hydro power plants Xiaowan and Jinanqiao via four 500 kV ac transmission lines. This local AC/DC system would be connected to the other part of Yunnan power grid through four short 500 kV ac transmission lines (shorter than 20 km).

In summer 2010, after Yun-Guang UHVDC system would be bipolar commercial operated, a huge synchronous AC/DC parallel transmission system consisting of 4 HVDC systems

(±500 kV Tian-Guang, Gui-Guang I and Gui-Guang II HVDC systems and ±800 kV Yun-Guang UHVDC system) would emerge in China Southern Power Grid. All of these four HVDC systems and the more than 8 500 kV ac transmission lines parallel with them are built for the task of power transmission from West to East in the southern area of China. Based on the AC/DC system configurations of China Southern Power Grid in years 2010 to 2012 a large amount of load flow calculation and stability simulation were performed. In order to improve the power delivery capability from Yunnan to Guangdong in the heavy load season, the local AC/DC systems consisting of Chuxiong Converter Station and two hydro power plants shall operate separately or islanded from the other parts of the synchronous ac power grid. Comparing with the rated dc power of 5000 MW the ac system in the islanded local AC/DC system would be very weak. The Short Circuit Ratio (SCR) at the Chuxiong station ac busbar could be even lower than 1.7.

Operation under very low SCR would lead to very high ac overvoltages at the Chuxiong station ac busbar in the case of bipolar dc load rejection. Mitigation methods including upgrades of main equipments and coordination of DC Control and Protection logics against the very high ac overvoltages were introduced in [2]. Another disadvantage of low SCR to dc operation is the potential low order harmonic resonance between the ac network impedance and the ac filters in the converter station. In order to meet the ac harmonic voltage distortion limits special ac filter configurations are considered for the Chuxiong station.

III. Converter Station Design

A. Arrangement of Thyristor Valves

The Yunnan-Guangdong ±800 kV UHVDC project is designed based on the proven technology and the project experiences in the ±500 kV, 3000 MW HVDC systems. However, if the classical configuration of one 12-pulse bridge per pole in common bipolar HVDC systems would also be employed in the Yun-Guang UHVDC system, the increased voltage and power stress would bring unconquerable challenges to design of key equipments, such as, converter transformer. The solution for Yun-Guang UHVDC Project is a series connection of two 12-pulse bridges with 400 kV rated voltage each to reach the rated dc voltage of 800 kV per pole (see Figure-1).

Each 12-pulse thyristor valve is arranged in one individual valve hall. Two valve halls of one pole are connected through dc wall bushings and dc disconnectors. There are totally four valve halls in one station. The valve towers of the Yun-Guang Project are arranged as double-valves, which are suspended from the ceiling of the valve hall. Hence, in each hall of one 12-pulse valve group there are six towers.

The well-proven modular design with stacked thyristors and heat-sinks is adopted for the UHVDC application. One thyristor valve with two modular units comprises four valve sections and is composed by 60 series connected thyristors. The converters of the Yun-Guang Project are based on 5 inch direct light-triggered thyristor (LTT) technology which has already been successfully implemented in several other HVDC schemes in China.

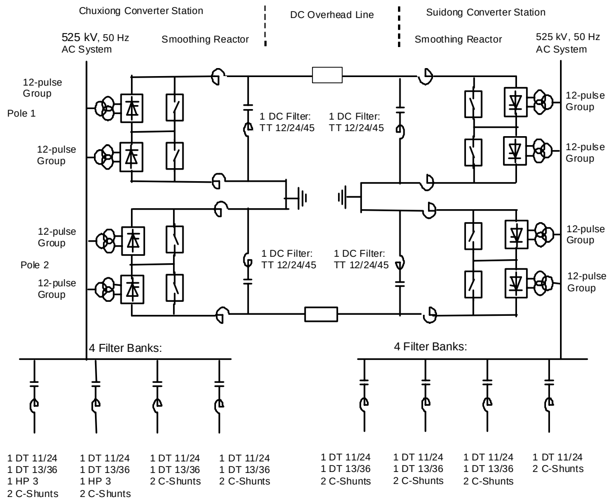

Figure-1: Single Line Diagram of Yun-Guang UHVDC System

For an uninterruptible power transfer during block or deblock of any individual 12-pulse valve groups, dc bypass switches and group disconnect switches are included. The dc current could be commutated between the thyristor valves and the bypass path by the bypass breakers. However, no dc current interruption capability is required for this purpose, as the converter will be controlled to compensate the dc current in the breakers. Only a small ac current driven by the 12-pulse harmonic voltage of the bridge has to be interrupted.

B. Arrangement of Smoothing Reactors

Considering the very high insulation requirements for the oil-type smoothing reactors, dry-type smoothing reactors with 75 mH inductance of each coil are used in Yun-Guang UHVDC project. The total inductance of 300 mH per pole per station is supplied by four 75 mH coils. In the steady state operation the four smoothing reactor coils will have the same smoothing effect for the harmonic currents, so long as they are connected in series with thyristor valves in the dc circuit. For a more economical and technically feasible installation of all four coils, two of them are installed on the high voltage dc bus and the others on the neutral bus. All of the four coils of one pole have the identical design and therefore only one spare coil is enough for one station. The only difference between the coils for high voltage and neutral bus is the insulation levels to ground (support insulators). Additionally, for protection against lightning surge stresses from the dc lines, the coils installed at the 800 kV bus are directly protected with parallel surge arresters.

From this arrangement another benefit can be get for the system design: the harmonic voltage drop across the neutral bus reactor (connected to the electrode line) significantly reduces the harmonic voltage to ground stresses of the other converter equipments. This especially affects the steady state voltage ripple of the 800 kV converter transformers.

C. Insulation Requirements Investigation

An important and challenging subject for the arrangement shown in the Figure-1 is the overall arrester arrangement in the converter station. The resulting identical overall arrester protection scheme as used for both Chuxiong and Suidong stations of the Yun-Guang UHVDC Project is shown in the Figure-2.

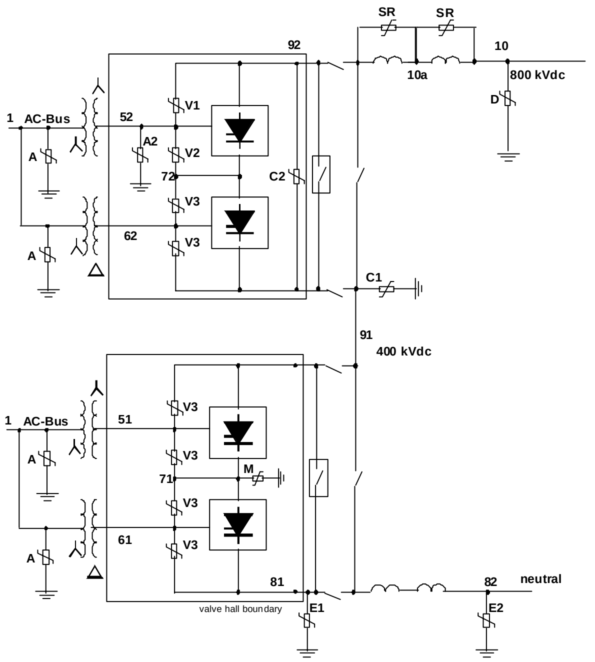

Figure-2: UHVDC Arrester arrangement

The ZnO-arresters type 'A2' will be installed on the secondary side of the star group converter transformer 800 kV winding to ground. Because of the installation of smoothing reactors on the neutral bus the crest continuous operating voltage (CCOV) of this type of arrester is reduced which allows lower protective and insulation levels. Without this type of arrester, a series connection of multiple arresters would define the protective level at this location which would lead to higher protective levels.

However, installation of smoothing reactors on the neutral bus leads to increased insulation level to ground on their valve side terminals (location 81 in Figure-2). Also during transient disturbances the voltage to ground can rise and hence additional arresters can be useful to limit voltage stresses on the equipment, e.g. arrester type M at the twelve-pulse group mid-point. Another type of this arrester, type ‘C1’ is connected in between both 12-pulse groups at the 400 kV bus. This arrester is connected to ground and is required for operating condition with the high voltage (upper) 12-pulse valve group out of service. It will limit incoming switching surge to adequate values for the 400 kV bus.

The arresters type ‘SR’ is connected across the terminals of each smoothing reactor coil on the 800 kV bus. During typical disturbances in the dc circuit (e.g. commutation failures due to ac faults at inverter station) this arrester should not become active. Its major task is to protect the coils in case of lightning surges coming from the dc OHL lines into the dc switchyard.

The Chuxiong station is located at 1850 m above sea level. Reduced air density for such an installation location can affect the external insulation withstands strength, namely the air clearances. Therefore it is essential to verify adequateness of equipment design and layout arrangement.

The equipments connected to 500 kV exposed at ac side are determined to be designed for the increased external insulation levels as follows: SIL=1300 kV/ BIL=1800 kV. It should be noted that these external insulation levels are valid for equipment type tests conducted in test labs below at 0 m above sea level.

Similarly, for the equipments at dc side the safety margins according to IEC 60071-5 are adequate for installations on altitudes up the 1000 m above sea level. However, for an altitude of 1850 m the IEC Standard 60071-2, 1996 requires an additional correction factor (depending on factor m) which has to be taken into account for clearance calculations. It is important to note that a general increase of insulation levels by this factor is not suitable since this would also affect internal insulation, which is altitude independent. Therefore only the air clearances of air insulated equipment (insulators and bushings) as well as the layout of dc valve hall and dc yard has to be verified to include sufficient safety margins.

One major challenge for design of main equipment for UHVDC applications up to 800 kV is the choice of adequate external insulation material. Installations in heavily polluted areas and operation conditions in combination with rain or fog show that polluted insulators may be subjected to highly non-linear voltage distribution along the insulator surface. Local increase of electrical field strength may lead to corona, partial flashovers or finally complete flashovers. A hydrophobic surface, such as silicone surface, will neither allow a continuous water film along the surface nor build-up of a low-resistive pollution layer. Both are basically responsible for unequal voltage distribution and flashover problems.

The external insulation of all the equipments on the 800 kV busbars is designed using silicone surfaces. This includes for example post insulators, surge arresters, dc PLC coupling capacitors, dc voltage dividers, dc measuring shunts, dc disconnectors, dc bypass breakers as well as dc wall bushings. The excellent experiences gained with this insulation surfaces due to its hydrophobic effects provide a solid basis for reliable and safe operation for polluted areas at high dc voltage levels.

An improvement in the flashover performance can also be achieved by simply increasing the creepage distance. However, if using porcelain solutions based on increased creepage distance requirements for the equipments on the 800 kV dc busbars, manufacture dimensions of these equipments would be very large (e.g. post insulator heights of approx. 14 to 15 m). These impose problems of mechanical strength especially regarding weight in combination with seismic design requirements.

D. AC Filters

For the ac systems connected to the Chuxiong and Suidong stations of the Yun-Guang UHVDC project, the following ac filter performance requirements are specified:

- individual harmonic distortions:

3rd/5th Dn ≤ 1.25% / ≤ 1.0%
odd harmonics Dn ≤ 1.0% / ≤ 0.8%
even harmonics Dn ≤ 0.5% / ≤ 0.5%

- total harmonic distortion: Drms ≤ 1.75% / ≤ 1. 5%
- telephone harmonic form factor: THFF ≤ 1.0% / ≤ 1.0%

For the Chuxiong station considering the large equivalent harmonic impedance and the high contents of background harmonics in the islanded operation mode, low-order non-characteristic harmonic filters (3^{rd} and 5^{th} harmonics) are required. However, in the normal operation mode, these low order harmonic filters are not needed.

Due to low reactive power consumptions of dc converters in the low dc load range only few ac filter capacities could be in operation. In order to reduce the individual harmonic distortions of the 3^{rd} and the 5^{th} harmonics for low dc power transfers in islanded operation mode, triple tuned ac filters type A 5/11/24 and type B 3/13/36 would be required in the Chuxiong station. However, for increasing dc loads, two double tuned ac filters type A 11/24 and type B 13/36 in combination with a single tuned 3^{rd} harmonic filter are fully adequate to fulfil the harmonic performance requirements. The 3^{rd} harmonic filter provides a low impedance branch for the large ac currents of low order harmonics, such as 2^{nd}, 3^{rd} and 5^{th} harmonics. Comparing both filter design schemes, the configuration with double tuned ac filters (type A 11/24 and type B 13/36) and single tuned 3^{rd} harmonic filter provides large economical benefits and is selected as basis for design calculation in details.

For the Suidong station, using the double tuned ac filters of the tuning frequencies only on the characteristic harmonics of 11^{th}, 13^{th}, 24^{th}, and 36^{th}, the specified ac filter performance could be met.

The conservative filter performance calculation of both stations were done with all worst conditions taken into account, such as large filter detuning factors, great power frequency deviation, high background harmonics and huge low order ac harmonic impedances of the islanded Chuxiong side's ac system. The performance limits at the ac busbars of both Chuxiong and Suidong statons shall be met during whole load range with any one subbank out of service.

In order to meet the requirements of ac filter performance and reactive power compensation, 4 A-type, 4 B-type, 2 C-type ac filters and 8 C-shunts (all 187 MVAr each) would be installed in the Chuxiong station. And the Suidong station would be equipped with 4 A-type, 3 B-type filters (190 MVAr each) and 8 C-shunts (210 MVAr each).

E. DC Filters

Harmonic voltages which occur on the dc side of a converter station cause ac currents which are superimposed on the direct current in the transmission line. These alternating currents of higher frequencies can create interferences in neighbouring telephone systems despite limitation by smoothing reactors. DC filter circuits, which are connected in parallel to the station poles, are an effective tool for combating these problems.

In the past the common dc filter configurations are the single and the double tuned filters with or without the high-pass feature. In the new scheme triple tuned dc filters are also used due to various technical and economical advantages. The determination of filter configuration is made on the basis of achieving the smallest equivalent disturbing current caused by the HVDC line and with minimum filter costs. The most cost-intensive element in a dc filter is the high voltage capacitor. Therefore an effort is always to be made in the design of dc filter circuits to optimize the cost of high voltage capacitors.

Since the characteristic harmonic currents have the largest amplitudes, the dc filters are usually matched to these harmonics (i.e. ordinal numbers 12, 24, 36, 48, ...). For the Yun-Guang Project one triple tuned dc filter is used per each pole and station. The triple tuned arrangement allows very effective filtering by tuning to 12^{th}, 24^{th} and 45^{th} harmonic frequency. The harmonic impedance characteristic is shown in Figure-3 and shows the low impedance characteristics at the four lowest characteristic harmonics up to the 48^{th} harmonic. As a result, in the normal operation of Yun-Guang UHVDC project with all dc filters in service, this triple tuned dc filter 12/24/45 would have the similar harmonic current reduction performance as if the normal configuration of two double tuned dc filters (12/24 and 36/48) per pole were used. One high voltage capacitor could therefore be saved in each pole and station.

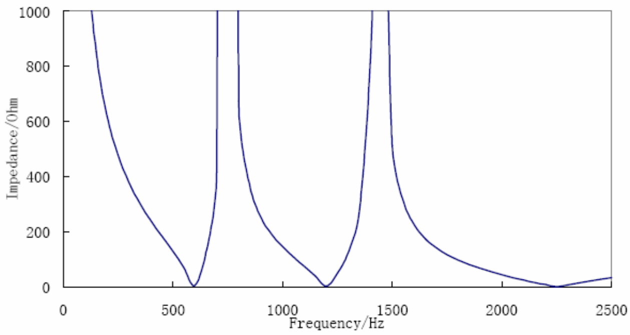

Figure-3: Impedance of DC Filters (TT 12/24/45)

Importance for the dc filter performance at bipolar operation is to ensure a symmetric configuration between both poles in order to minimize the ground mode currents. In case any filter branches are out of service, the dc control will automatically take necessary measures to build a symmetric configuration. The equivalent disturbing current and telephone interference could be therefore limited to its possible minimum.

IV. CONCLUSIONS

This paper provides an overview of the converter station design of the world's first ±800 kV UHVDC link - Yunnan-Guangdong UHVDC project.

It describes and discusses the technical challenges caused by the special location and operation conditions. The special consideration and design practices in the overall converter station arrangements, the insulation coordination, the ac filters and the dc filters are also summarized in it.

References

[1] S. Balbierer, M. Haeusler, V. Ramaswami, Rao Hong, Shang Chun, and Shang Tao, *Basic Design Aspects of the 800 kV UHVDC Project Yunnan-Guangdong*, the Sixth International Conference of Power Transmission and Distribution Technology, Guangzhou, China, Oct. 2007.

[2] M. Haeusler, D. Zhang, W. Liu, X. Jin, and H. Cai, *Aspects of Islanded Operation of the 800 kV UHVDC Project Yunnan-Guangdong*, the Sixth International Conference of Power Transmission and Distribution Technology, Guangzhou, China, Oct. 2007.

Donghui Zhang
Siemens AG, PTD H123
91050 Erlangen
Germany
email: donghui.zhang@siemens.com

Donghui Zhang, born in 1973, received his B. degree from Tsinghua University in 1997 and Dipl.-Ing. degree in Electrical Engineering from University of Erlangen-Nuremberg, Germany, in 2001. Since he joined Siemens AG in 2001, he has been working on HVDC system engineering for many HVDC projects world wide.

Marcus Haeusler
Siemens AG, PTD H123
91050 Erlangen
Germany
email: marcus.haeusler@siemens.com

Marcus Haeusler, born in 1966, received his Dipl.-Ing. Degree in Electrical Engineering from University of Karlsruhe, Germany, in 1992. Since he joined Siemens AG in 1992, he has been working on HVDC system engineering for many HVDC projects world wide. Currently he is responsible for HVDC system engineering.

Hong Rao
CSG Technology Research Center
6 Huasui Road,
Guangzhou, China
email: raohong@csg.cn

Hong Rao, received his B.Sc.(Eng.) degrees in Electrical Engineering from Huazhong University of Science and Technology in 1983. He is currently a senior engineer with CSG Technology Research Center(TRC). His research interest is in AC&DC power system ,HVDC, and simulation.

Shang Chun

EHV Power Transmission Company
116 Tianhe Road,
Guangzhou, China
email: shangchun@spsc.com.cn

Shang Chun, born in 1966, received his Master Degree in HV Electrical Engineering from Wuhan University of Hydrolic and Electrical Engineering China in 1993. He has been working on HVDC system engineering and operation for years. Currently he is responsible for UHVDC system engineering project management.

Shang Tao
EHV Power Transmission Company ,
116 Tianhe Road,
Guangzhou, China
email: shangtao@spsc.com.cn

Shan Tao, born in 1969 received his Bachelors Degree in Power Electrical Engineering from the Huazhong University of Science and Technology and work for HVDC since 1994. Currently he is responsible for Currently he is responsible for UHVDC system engineering project management.