J Electr Eng Technol.2015; 10(4): 1773-1779
http://dx.doi.org/10.5370/JEET.2015.10.4.1773

ISSN(Print) 1975-0102
ISSN(Online) 2093-7423

Comparison of Insulation Coordination Between ±800kV and ±1100kV UHVDC Systems

Dong-ju Wang* and Hao Zhou†

Abstract – Insulation coordination is a key problem in UHVDC systems in terms of safety and cost. Although high-voltage ±1100kV UHVDC projects are being planned in China, the characteristics and key points of high-voltage systems have not yet been analyzed. This study aims to improve the safe, effective operation of these high-voltage power transmission systems. First, we analyzed two typical insulation coordination schemes used in ±800kV UHVDC systems in China. Next, we used the two typical ±800kV insulation coordination schemes as a reference to analyze the ±1100kV UHVDC system. Finally, we compared these schemes and proposed an effective insulation coordination solution, as well as developing principles for ±1100kV UHVDC systems. Our findings indicate that the points enduring the highest voltage in the system should be protected separately by special arresters. Our analysis of the insulation coordination of ±800kV and ±1100kV UHVDC systems concluded that, in ±1100kV UHVDC systems, the main goal of insulation coordination is to lower the insulation level of points enduring the highest voltage. However, in a ±800kV UHVDC system, the main goal is to reduce the cost of manufacture for arresters, as well as the space occupation in the valve hall, with an acceptable insulation level.

Keywords: Insulation coordination, UHVDC, Arrester scheme, Insulation level, Protection level, Insulation margin

1. Introduction

As China undergoes rapid development, there is a growing demand for power. Therefore, there is an increasing need for higher power transmission capacity and longer transmission distances. To meet this demand, five ±800kV UHVDC power transmission projects have been put into operation. More transmission projects with higher voltage levels of ±1100kV UHVDC are also planned. For safe and effective installation and operation, it is important to study their insulation coordination design, the key technology in a ±1100kV UHVDC system.

The study of insulation coordination is fundamental to power transmission projects, as it defines the technical requirements to ensure the safety and economical performance of these power systems. With higher system voltage levels, the insulation coordination design becomes even more important. Particularly for UHVDC transmission systems, with the highest voltage level in HVDC transmission in the world, a sound insulation coordination design not only ensures the project's safety in operation, but also lowers construction costs [1-3]. A reasonable insulation coordination solution can reduce the insulation requirements of equipment, especially for high-voltage conditions.

† Corresponding Author: College of Electrical Engineering, Zhejiang University, China. (zhouhao_ee@zju.edu.cn)
* College of Electrical Engineering, Zhejiang University, China. (shuwei1204@163.com)
Received: April 22, 2014; Accepted: February 27, 2015

Since the development of HVDC transmission systems in the 1950s, valuable contributions to insulation coordination for HVDC systems have already been made, most of which were summed up from operational experiences, and protection devices involved valve type lightning arresters. Since the early 1980s, attention was mainly devoted to digital simulation of surges and the development and application of metallic oxide gapless surge arresters, due to their excellent protection properties. After 1990s, several studies have focused on insulation coordination for these three UHVDC projects [4, 5]. Other studies have discussed different arrester configurations for ±1100kV UHVDC projects [6, 7].

This study analyzes and compares the insulation coordination of ±800kV UHVDC and ±1100kV UHVDC systems, based on the overvoltage simulation results of 3 typical UHVDC power transmission projects in China: the ±800kV Xiangjiaba-Shanghai UHVDC project, the ±800 kV Yunnan-Guangdong UHVDC project, and the ±1100kV Zhundong-Sichuan UHVDC project.

In this study, we first compare two typical types of insulation coordination within the ±800kV Xiangjiaba-Shanghai UHVDC project and the ±800kV Yunnan-Guangdong UHVDC project. Next, we discuss key issues in arrester configurations and the insulation coordination of UHVDC systems. Finally, we propose a reasonable insulation coordination solution, as well as principles for ±1100kV UHVDC systems.

The remainder of this article is organized as follows:

Section II presents the arrester configuration for UHVDC systems. Section III introduces the insulation coordination in the ±800kV Xiangjiaba-Shanghai UHVDC project and the ±800kV Yunnan-Guangdong UHVDC project. Section IV discusses the insulation coordination focal points in UHVDC projects. Section V analyzes different arrester configurations for the Zhundong-Sichuan UHVDC project, compared to results from former sections. Finally, section VI provides conclusions.

2. Arrester Configuration in UHVDC Systems

Overvoltage, especially switching overvoltage, mainly determines insulation coordination. In UHVDC systems, arresters are always used to restrict overvoltage, and arrester configuration is an important part of insulation coordination [8-10].

The basic principles of arrester configurations are as follows:

1) The insulation at the AC side of the converter transformer is protected by AC arresters, while the DC side is protected by DC arresters;
2) Some important equipment at the converter station, such as converter transformers, valves, and so on, is directly protected by nearby arresters;
3) For other equipment that is not directly protected by a single arrester, protection can be achieved with several arresters connected in a series; for example, the phase-to-earth insulation of a wall bushing at the valve side of the converter transformer can be protected by arresters connected in a series.

3. Insulation Coordination in ±800kV UHVDC Systems

This section introduces arrester configurations for the two projects under review: the Xiangjiaba-Shanghai ±800 kV UHVDC project and the ±800kV Yunnan-Guangdong UHVDC project. Based on the arrester configuration and overvoltage simulation results from these two projects, we then propose the calculated protection performance of surge arresters in converter stations. Finally, we present the protection and insulation levels for equipment at these converter stations.

3.1 Arrester scheme

Five ±800kV UHVDC power transmission projects have already been completed and put into operation in China. There are two typical arrester configurations in these projects. ABB designed the arrester scheme for the Xiangjiaba-Shanghai ±800kV UHVDC project, and Siemens designed the arrester scheme for the Yunnan-Guangdong ±800kV UHVDC project. The differences between these two configurations are as follows: in ABB's design, the top of converters (point 5 in Fig. 1) is directly protected by arrester CBH, and point 1 is protected by arrester MH and V2 in series. However, in Siemens' design, point 1 is directly protected by arrester A2, and point 5 is protected by arrester CB1A and C2 in a series.

The complete arrester configurations for the two projects are shown in the following figures. Fig. 1 presents the arrester configuration for the ±800kV Xiangjiaba-Shanghai UHVDC project, and Fig. 2 presents the arrester configuration for the ±800kV Yunnan-Guangdong UHVDC project. The terms found within the each figure are defined in Table 1.

It is evident that the main parts of the arrester

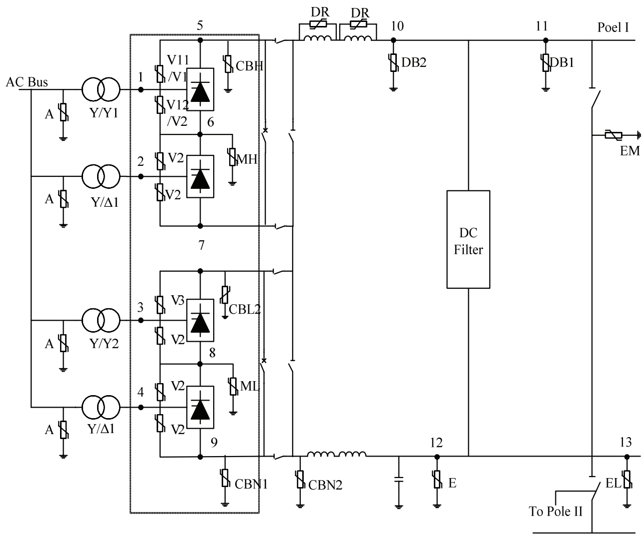

Fig. 1. Arrester scheme in the ±800kV Xiangjiaba-Shanghai UHVDC project

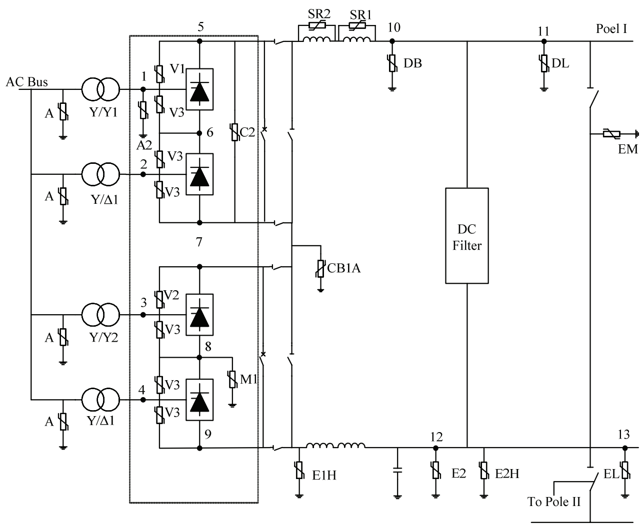

Fig. 2. Arrester scheme in the ±800kV Yunnan-Guangdong UHVDC project

Table 1. Definition of arresters for converter stations

Arresters	Description
A	AC bus arrester
V11/V12/V2/V3	Valve arrester
MH/ML/M1	Upper/Lower 12-pulse converter unit with 6-pulse bridge arrester
CBH	DC bus arrester of upper 12-pulse converter group (to earth)
A2	DC bus arrester of the connection bus between the High Voltage (HV) Y/Y converter transformer and the valve
CBL2/CB1A	DC bus arrester between the two 12-pulse groups
CBN1/CBN2/E1H	Neutral bus arrester at the valve side
DB1/DB2/DB/DL	DC pole bus/line arrester
DR/SR1/SR2	Parallel arrester of smoothing reactors
E/E2/E2H	Neutral bus arrester
EM	Metallic return bus arrester
EL	Electrode line arrester
C2	Arrester of upper 12-pulse converter group

configurations for the ±800kV Xiangjiaba-Shanghai and Yunnan-Guangdong UHVDC projects are similar, except for the arresters positioned to protect four different parts: the top of the upper 12-pulse converter group (point 5 in Fig. 1 and Fig. 2); two sides of the upper 12-pulse converter group (points 5 to 7); the 6-pulse bridge within the higher 12-pulse converter (point 6); and the connection bus between the High Voltage (HV) Y/Y converter transformer and the valve (point 1). The next section introduces various parts of the arrester schemes.

3.2 Differences in arrester configurations for the Xiangjiaba-Shanghai and Yunnan-Guangdong UHVDC projects

The arrester configurations that protect points 1, 5, 6, and 5 to 7 in Fig. 1 and Fig. 2 differ in these two projects, as follows:

3.2.1 Point 1

In the ±800kV Xiangjiaba-Shanghai UHVDC project, the connection bus between the High Voltage (HV) Y/Y converter transformer and the valve (point 1 in Fig. 1) is protected by arresters MH and V2 in a series. However, in the ±800kV Yunnan-Guangdong UHVDC project, arrester A2 protects the bus directly.

The advantage of the former is that there is only one arrester (MH), which requires less space in the valve hall and is therefore more economical. However, the downside to this configuration is that the protection level of arresters MH and V2 in a series is higher than that of arrester A2. Thus, the requirement for a converter transformer bus at point 1 is higher. In contrast, the latter's requirement for a converter transformer bushing at point 1 is lower. However, 3 A2 arresters are needed for the 3 phases of the converter transformer. Therefore, more space in the valve hall is required to place these arresters.

In this case, the utilization rate of each A2 arrester is only one third, since the valves are equal in conduction in turns at working time. This rate is lower than that of arrester MH in the Xiangjiaba-Shanghai project. To reduce the protection level accordingly, the CCOV (Crest value of Continuous Operating Voltage) of arrester A2 can be lower, due to the low utilization rate.

3.3.2 Point 5

In the Xiangjiaba-Shanghai project, the top of the upper 12-pulse converter group (point 5 in Fig. 1) is directly protected by arrester CBH. However, in the Yunnan-Guangdong project, it is protected by arresters CB1A and C2 in a series. The former's advantage is that the protection level of the DC bus at point 5 could be lower than in the latter. The shortcoming is that an arrester CBH is needed, requiring more space.

3.2.3 Point 6

In the Xiangjiaba-Shanghai project, the DC bus between the 6-pulse bridges in the upper 12-pulse converter (point 6 in Fig. 1) is directly protected by the arrester MH. However, in the Yunnan-Guangdong project, the DC bus is protected by arresters CB1A and V2 in a series. Similar to the description above for point 5, the former's advantage is that the protection level of the DC bus at point 6 could be lower than the latter, and the shortcoming is that arrester MH is needed, which requires more space.

3.2.4 Points 5 to 7

In the Xiangjiaba-Shanghai project, valve arresters in a series protect the two sides of the upper 12-pulse converter group (points 5 to 7). The underlying principle is that at least one valve out of three is in conduction when the converter is working. This means that the protection level of the upper 12-pulse converter group is equal to that of the V11 and V2 valve arresters. In the Yunnan-Guangdong project, arrester C2 protects the converter directly, making the protection level lower than that of the Xiangjiaba project. The system is also in operation through a half-pole mode with the upper 12-pulse converter, which is protected by C2 in the Yunnan-Guangdong project and by CBH in the Xiangjiaba-Shanghai project. In this case, the latter is safer than the former. Again, however, an arrester C2 is needed, which requires more space.

3.3 Insulation margin between protection level and insulation level

The protection levels of arresters can be obtained from results of the overvoltage simulation. However, the insulation levels of equipment protected by arresters should be higher than the protection level, in consideration of the insulation performance loss from insulation material burn-in, arrester burn-in, weather factors such as rain, fog and moisture, and environmental factors such as pollution and high altitude. Therefore, the required insulation levels of equipment may be obtained by multiplying extra coefficients according to the different equipment and surge types based on these protection levels. Such coefficients are called insulation margin coefficients, and the margin is always expressed in a percentage, called the insulation margin. An evaluation of the insulation margin in each UHVDC system is provided below.

An appropriate insulation margin is important to UHVDC systems. Small insulation margins make the system unsafe, but large margins waste manufacturing cost. Therefore, the characteristics of the equipment, as well as the environment in which it is installed, should be taken into consideration.

As a reference, the insulation margins in HVDC systems are listed in Table 2 [11].

Table 2. Insulation margin in HVDC systems

Equipment	Insulation Margin		
	Switching	Lightning	Fast Transient
Valve	15%	15%	20%
Converter transformer	15%	20%	25%
Smooth reactor	15%	20%	25%
Equipment in valve hall	15%	15%	20%
Equipment in DC yard	15%	20%	25%

In UHVDC systems, thyristor valves are better designed and manufactured, the valve control system is more advanced, and the environment within the valve hall is maintained with more stability than those in HVDC systems. Furthermore, a lower valve insulation level reduces costs for valve hall construction, lowering the valve insulation margin compared to that of HVDC systems. Table 3 lists the insulation margins in UHVDC systems.

Table 3. Insulation margin in UHVDC systems

Equipment	Insulation Margin		
	Switching	Lightning	Fast Transient
Valve	10%	10%	15%
Converter transformer	15%	20%	25%
Smooth reactor	15%	20%	25%
Equipment in valve hall	15%	15%	20%
Equipment in DC yard	15%	20%	25%

3.4 Protection and insulation levels in Xiangjiaba-Shanghai and Yunnan-Guangdong UHVDC projects

Tables 4 and 5 display protection levels and insulation levels in the Xiangjiaba-Shanghai and Yunnan-Guangdong UHVDC projects, according to arrester scheme and overvoltage simulation results [12].

Table 4. Protection and Insulation Levels in ±800kV Xiangjiaba-Shanghai UHVDC projects

Pos	Protected By	LIPL/SIPL (kV)	LIWL/SIWL (kV)	Marg (%)
1	MH+V2	1454/1386	1800/1600	24/16
2	CBL2+V2	1087/1079	1400/1300	29/20
3	ML+V2	813/871	1050/1050	29/21
4	CBN1+V2	826/823	1050/1050	27/28
5	CBH	1426/1385	1800/1600	26/16
6	MH	1078/1027	1350/1200	25/17
7	CBL2	752/717	950/850	26/19
8	ML	495/485	650/600	31/24
9	CBN1/CBN2	458/437	550/550	20/26
10	DB	1625/1391	1950/1600	20/15
12	Min(E,EM,EL)	386/341	500/450	30/32

Table 5. Protection and Insulation Levels in ±800kV Yunnan-Guangdong UHVDC projects

Pos	Protected By	LIPL/SIPL (kV)	LIWL/SIWL (kV)	Marg (%)
1	A2	1344/1344	1800/1600	34/19
2	CB1A+V3	-/1101	1550/1300	-/18
3	M1+V3	-/830	1300/1050	-/27
4	E1+V3	-/631	950/750	-/19
5	CB1A+C2	-/1412	1800/1600	-/19
6	CB1A+V3	-/1101	1550/1300	-/18
7	CB1A	791/706	1175/950	49/35
8	M1	435/435	750/550	72/26
9	E1	320/263	450/325	41/24
10	D	1579/1328	1950/1600	23/20
12	E2	320/263	450/325	41/24

4. Key Points of Insulation Coordination in UHVDC Projects

From the two typical arrester schemes introduced in section 3, it can be concluded that all valves and every point of junction within converter stations should be protected by arresters, either directly or indirectly. In addition, this protection should consist of no more than 2 arresters.

The higher the insulation level of the equipment, the greater the manufacturing costs, especially for UHVDC systems. Points 1, 5, 10, and 12 are the highest insulation level points in UHVDC systems. The rated voltage at these points is much higher than that of ±500kV HVDC systems. Therefore, insulation levels at these points are the focal points for insulation coordination of UHVDC systems. Overvoltage on these points should be as low as possible so that the insulation level of these points can be much lower.

Moreover, attention should also be paid to points 2 and 6, whose operating voltage is lower than that of those points above, but higher than other points, except for points 1 and 5. Lowering the insulation level of these points also helps reduce equipment manufacturing cost and improves the stability of the UHVDC system.

The operating voltages of other points are lower, while the equipment at these points is easier to manufacture than for the aforementioned points in section 4. The rated operating voltage of the neutral bus is the lowest in the UHVDC system. It is always less than 50kV. However, the protection levels of the arresters E, EM EL, E1 and E2 installed on the neutral bus are much higher than the rated operation voltage. This reduces the difficulty of the neutral bus arrester design and raises reliability. When the neutral bus insulation level is lower, it is more easily threatened by overvoltage, reducing its reliability. In contrast, a higher neutral bus insulation level can naturally prevent lower overvoltage, as is the case with a majority of overvoltage cases in operation.

The insulation level of the neutral bus should be appropriately high. This can improve reliability of the UHVDC system, while at the same time limiting the cost of equipment manufacture for the neutral bus.

Once a proper protection level of neutral bus arresters is selected, the most important factor is selection of an arrester's energy capacity to absorb overvoltage energy.

In conclusion, the focal point of UHVDC system insulation coordination is protection for points where operating voltage is higher, such as points 1, 2, 5, 6, 10, and so on. The insulation levels of equipment at these points should be carefully considered and properly designed. Energy capacity design is the most important factor to consider for neutral bus arresters.

Based on this conclusion, the next section details insulation coordination in ±1100kV UHVDC systems.

5. Insulation Coordination in ±1100kV UHVDC Systems

According to the plan, the Zhundong-Sichuan ±1100kV UHVDC bipolar power transmission project has a rated capacity of 10450 MW, a rated DC voltage of 1100kV, and a rated DC current of 4750A.

Compared with ±800kV UHVDC systems, the rated voltage of ±1100kV systems is much higher, highlighting the problem of insulation level design. This problem then affects the details of insulation coordination design.

5.1 Analysis of the Arrester Scheme in ±1100kV UHVDC Systems

To design the arrester scheme, we can first refer to ±800kV UHVDC systems. Based on conclusions in Section 4, Section 5 focuses on the insulation levels of points 1, 2, 5, 6, and 10. Based on arrester configurations of the ±800kV Xiangjiaba-Shanghai and Yunnan-Guangdong UHVDC projects, protection and insulation levels calculation results are listed in Tables 6 and 7, respectively.

Table 6. Protection and Insulation Levels in the ±1100kV Zhundong-Sichuan UHVDC project with arrester configuration of the Xiangjiaba-Shanghai UHVDC project.

Pos	Protected By	LIPL/SIPL (kV)	LIWL/SIWL (kV)	Marg (%)
1	MH+V2	2037/1945	2500/2250	25/16
2	CBL2+V2	1577/1563	1950/1800	24/15
3	ML+V2	1227/1230	1550/1550	26/26
4	CBN1+V2	1004/1011	1300/1200	29/19
5	CBH	2038/1946	2500/2250	23/16
6	MH	1504/1436	1850/1700	23/18
7	CBL2	1031/984	1300/1200	26/22
8	ML	681/651	850/850	25/31
9	CBN1/CBN2	458/432	550/550	20/27
10	DB	2162/1859	2600/2150	20/16
12	Min(E,EM,EL)	478/380	650/450	36/18

Table 7. Protection and Insulation Levels in the ±1100kV Zhundong-Sichuan UHVDC project with arrester configuration of the Yunnan-Guangdong UHVDC project.

Pos	Protected By	LIPL/SIPL (kV)	LIWL/SIWL (kV)	Marg (%)
1	A2	1837/1819	2250/2100	22/15
2	CB1A+V3	1575/1548	1950/1850	24/20
3	M1+V3	1181/1187	1550/1400	31/18
4	E1+V3	958/996	1200/1200	25/20
5	CB1A+C2	2162/1859	2600/2150	20/16
6	CB1A+V3	1575/1548	1950/1850	24/20
7	CB1A	1031/984	1300/1200	26/22
8	M1	637/623	850/750	33/20
9	E1	414/432	550/550	33/27
10	D	2162/1859	2600/2150	20/16
12	E2	489/389	650/550	33/41

It is evident that the protection and insulation levels of ±1100kV UHVDC systems are very high. Furthermore, protection levels are in proportion to the system's rated voltage. Compared to ±800kV UHVDC systems, there are 2 differences in ±1100kV UHVDC systems:

1. The insulation margins in ±1100kV UHVDC systems are lower than those in the ±800kV systems, especially at points 1, 5, and 10.
2. Under different arrester configurations, points 1 and 5 do not share the same insulation levels as the ±800kV UHVDC systems.

As discussed in section 4, the insulation of points 1, 2, 5, 6, and 10 is the key component of the ±1100kV UHVDC systems. It is important to limit the insulation level of these points to as low a level as possible. Table 6 and 7 demonstrate this, as follows:

1. Under the arrester configuration of the Xiangjiaba-Shanghai project, the insulation level of point 1 is higher than that under the arrester configuration of the Yunnan-Guangdong project. This is because there is

no arrester installed at point 1 in the former, but there is an arrester (A2) installed at point 1 in the latter. Arrester A2 only endures the highest voltage for about half of the time in a power frequency cycle, but CBH endures the voltage for the full cycle. This means that the protection level of arrester A2 is lower than that of arrester CBH, despite the same CCOV for points 1 and 5. Thus, the insulation level of point 1 with arrester A2 is lower. Point 1 is on the valve side of the converter transformer, so that there are 6 wall bushings. A higher insulation level requirement makes the cost of bushing manufacture higher, especially for such a high voltage level. Furthermore, the stability of this point in the former is lower than the latter because it endures a higher overvoltage.

2. Similar to point 1, under the arrester configuration of the Yunnan-Guangdong project, the insulation level of point 5 is higher than that under the arrester configuration of the Xiangjiaba-Shanghai project. Arrester CBH should protect point 5 directly in order to decrease the cost of wall bushings and increase the stability of the system.
3. Similarly, the insulation level of point 6 under the arrester configuration of the Yunnan-Guangdong project is higher than that under the arrester configuration of the Xiangjiaba-Shanghai project. Arrester MH is also needed in the ±1100kV UHVDC system.
4. Arrester C2 in the arrester configuration of the Yunnan-Guangdong project is useful to protect the upper 12-pulse converter in half-pole operation mode. However, it is not necessary when arresters MH and CBH are installed.
5. The insulation level of point 10 under these two arrester confutations is similar.

In conclusion, in ±1100kV UHVDC systems, points 1, 5, and 10 should be directly protected by arresters. Considering

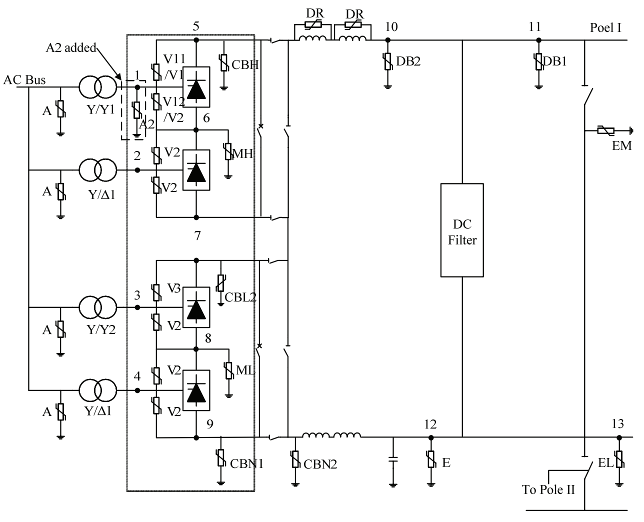

Fig. 3. Suggested arrester scheme in the ±1100 kV Zhundong-Sichuan UHVDC project

the advantages of these two arrester configurations, the suggested arrester scheme for ±1100kV UHVDC systems can be designed based on the Xiangjiaba-Shanghai project, with arrester A2 added at point 1. This configuration is shown in Fig. 3.

5.2 Comparison of Insulation Coordination in ±1100 kV and ±800kV UHVDC Systems

According to the suggested arrester scheme, the protection and insulation level calculation results of key points 1, 2, 5, 6, and 10 in the ±1100 Zhundong-Sichuan UHVDC project are listed in Table 8.

Table 8. Protection and Insulation Levels in the ±1100kV Zhundong-Sichuan UHVDC project with different arrester schemes

Pos	Scheme	Protected By	LIPL/SIPL (kV)	LIWL/SIWL (kV)
1	Arrester A2 added	A2	1837/1819	2250/2100
2		CBL2+V2	1577/1563	1950/1800
5		Max(A2, DB)	2038/1859	2500/2150
6		MH	1504/1436	1850/1700
10		DB	2162/1859	2600/2150
1	No Arrester A2	MH+V2	2037/1945	2500/2250
2		CBL2+V2	1577/1563	1950/1800
5		CBH	2038/1946	2500/2250
6		MH	1504/1436	1850/1700
10		DB	2162/1859	2600/2150

Table 8 shows that the suggested arrester scheme reduces the protection and insulation levels of point 1 and point 5. Therefore, it makes the system more economical and stable.

Compared with the insulation coordination of ±800kV UHVDC systems, ±1100kV UHVDC systems require a more complex arrester scheme and a more thorough coordination principle. The key recommendations for this insulation coordination are that the points enduring the highest voltage in the system should be separately protected by special arresters. However, in ±800kV UHVDC systems, the points that endure the highest voltage can be protected by other arresters indirectly to lower the cost of arresters and reduce the space needed for arresters in the valve hall. In other words, in ±1100kV UHVDC systems, the key recommendation for insulation coordination is to lower the insulation level of points that endure the highest voltage. However, in ±800kV UHVDC systems, this scheme with arrester A2 added reduces the cost of arresters' manufacture and space occupation in the valve hall with an acceptable insulation level.

6. Conclusion

In this work, we compared two types of typical insulation coordination used in ±800kV UHVDC systems and proposed that the key recommendation for UHVDC system insulation coordination is to protect the points where the operating voltage is higher, such as points 1, 2, 5, 6, and 10, and so on. Finally, we proposed a reasonable insulation coordination solution as well as principles for ±1100kV UHVDC systems. The points that endure the highest voltage in the system should be separately protected by special arresters.

In terms of the insulation coordination of ±800kV and ±1100kV UHVDC systems, it can be concluded that in ±1100kV UHVDC systems, the key goal of insulation coordination is to lower the insulation level of points that endure the highest voltage. However, in ±800kV UHVDC systems, the key goal is to reduce the cost of arrester manufacture and space occupation in the valve hall with an acceptable insulation level. Although the arrester scheme for ±1100kV systems is more complex and requires more thorough coordination, it is no less attainable.

Acknowledgements

This paper is supported by National Basic Research Program of China (973 Program)(2011CB209405).

References

[1] Z. Yi-ying, J. Wei-ping and W. Ya-ni, “Influence of UHVDC Control and Protection Characteristics on Inner Overvoltage,” in *The International Conference on Electrical Engineering 2008* OKINAWA, JAPAN, 2008.

[2] D. Manling, X. Shijun, Z. Dandan, H. Hengxing, B. Minghui, H. Junjia, H. Ying, L. Xiaolin, and C. Zongyuan, “Influence of smoothing reacteor arrangement on transients of converter station for ± 500kV double-circuit HVDC system,” in *Power and Energy Society General Meeting, 2010 IEEE*, Minneapolis, MN, 2010, pp. 1-8.

[3] L. Hua, L. Fuchang, H. Junjia, L. Yuxin, Y. Huisheng, and Z. Zhigang, “Analysis and Simulation of Monopolar Grounding Fault in Bipolar HVDC Transmission System,” in *Power Engineering Society General Meeting, 2007. IEEE*, Tampa, FL, 2007, pp. 1-5.

[4] J. LV and J. ZHAO, “Study on the Overvoltage and Insulation Coordination of Yunnan-Guangdong ±800 kV UHVDC Transmission System,” *Southern Power System Technology*, pp. 18-22, 2009.

[5] D. NIE, W. MA and J. ZHENG, “Insulation Coordination for ±800 kV UHVDC Converter Stations,” *High Voltage Engineering*, pp. 75-79, 2006.

[6] H. ZHOU and D. WANG, “Overvoltage Protection and Insulation Coordination for ±1100 kV UHVDC Converter Station,” *Power System Technology*, vol. 36, pp. 1-8, 2012.

[7] H. Zhou, X. Deng, D. Wang, Y. Shen, X. Chen and K. SUN, “Overvoltage and Insulation Coordination for ±1100kV UHVDC Converter Station,” *High Voltage Engineering*, vol.39, pp. 2477-2484, 2013.

[8] Y. Han, H. Chen, Y. Lu, and L. Li, “Research on DC Transient Overvoltage and Insulation Coordination of ± 800kV Converter Station,” in *Power and Energy Engineering Conference* (*APPEEC*), *2011 Asia-Pacific*, Wuhan, 2011, pp. 1-4.

[9] F. Su, S. Yuan, D. Zhang, and H. Zhou, “Insulation co-ordination of UHVDC transmission lines,” in *Electric Utility Deregulation and Restructuring and Power Technologies* (*DRPT*), *2011 4th International Conference on*, Weihai, Shandong, 2011, pp. 259-265.

[10] F. Su and H. Zhou, “Simulation on lightning overvoltage of ± 800kV converter station,” in *Lightning (APL), 2011 7th Asia-Pacific International Conference on*, Chengdu, 2011, pp. 491-495.

[11] IEC, T. (2002). 60071-5 − 2002 Insulation co-ordination, part 5: procedures for high-voltage direct current (HVDC) converter stations.

[12] M. Haeusler, H. Huang and K. Papp, “DESIGN AND TESTING OF 800 kV HVDC EQUIPMENT,” in *Cigre Conference* Paris, 2008.

Dong-ju Wang He received M.S. degree in Zhejiang University, Hangzhou, China in 2008. He is curently working toward a PH.D. degree at the College of Electrical Engineering, Zhejiang University. His major research interests is overvoltage and insulation coordination of UHVDC system.

Hao Zhou He received Ph.D. degree in electrical engineering all from Zhejiang University, Hangzhou, China, in 2004. He is currently a professor at the College of Electrical Engineering, Zhejiang University. His major research interests includs overvoltage, insulation coordination, lightning protection, power market and its application.