Transmission Technologies and Operational Characteristic Analysis of Hybrid UHV AC/DC Power Grids in China

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Abstract. In order to solve the contradiction between demand and distribution range of primary energy resource, Ultra High Voltage (UHV) power grids should be developed rapidly to meet development of energy bases and accessing of large-scale renewable energy. This paper reviewed the latest research processes of AC/DC transmission technologies, summarized the characteristics of AC/DC power grids, concluded that China’s power grid certainly enter a new period of large-scale hybrid UHV AC/DC power grids and characteristics of “strong DC and weak AC” becomes increasingly prominent; possible problems in operation of AC/DC power grids was discussed, and interaction or effect between AC/DC power grids was made an intensive study of; according to above problems in operation of power grids, preliminary scheme is summarized as follows: strengthening backbone structures, enhancing AC/DC transmission technologies, promoting protection measures of clean energy accessing grids, and taking actions to solve stability problems of voltage and frequency etc. It’s valuable for making hybrid UHV AC/DC power grids adapt to operating mode of large power grids, thus guaranteeing security and stability of power system.

1. Introduction
The problem of world energy depletion became increasingly serious. The environment was worsened by a large number of fossil fuels such as oil consumption and so on, so it’s urgent to seek green renewable energy to replace traditional energy. In addition, concentrated energy resources distribution and reverse distribution between primary energy and load are the existing primary problems in China. To realize inter-regional rational utilization of energy and transport clean energy quickly and efficiently, State Grid Corporation of China (SGCC) boosts the power grid development strategy of “one ultra and four large” and focuses on the development of UHV AC and DC technology which support long-distance and large-capacity transmission[1-5]. China has already become the only country which UHV AC/DC power grid running at the same time because of the characteristics of mass inter-regional transmission power.

Power grid in China is during transitional period of “strong DC and weak AC”. Fire-new malfunction, such as UHVDC double blocking, is always occurring that has high demand for control ability of power grids. The arrival of hybrid UHV AC/DC power grids largely promote the ability of large-scale optimizing configuration of resources. This paper analyzes current problems which power grids come up against and puts forward reasonable suggestions combined with the actual operation condition of power grids security and reliability based on AC/DC transmission technology to provide effective references for construction of UHV power grids in the future.
2. The general situation of UHV AC/DC transmission technology

2.1. The current situation and study of UHVAC transmission technology

In recent years, China has been committed to research on key technologies of UHV and made the great breakthrough. It has done many deep studies, such as voltage controlled, debugging, operation areas[6], and SGCC have researched and developed a set of UHVAC transmission technology which owns independent intellectual property rights and masters key technology of UHVAC power transmission and transformation. SGCC has carried out more than 300 items on studying UHVAC transmission equipment and manufacture of UHV equipment. SGCC established the UHVAC testing base and SGCC’s simulation centre, creating the top level UHV experimental study system aimed at overcoming the technical problems in the operation of UHV transmission[7].

Table 1 lists some UHVAC transmission projects which have already been put into operation.

| UHVAC          | Voltages levels/kV | Transmission line/lines |
|----------------|--------------------|------------------------|
| Changzhi-Nanyang-Jinmen | 1000               | 2                      |
| Huaiian-Shanghai   | 1000               | 6                      |
| Zhejiang-Fujian    | 1000               | 6                      |
| Ximeng-Shandong    | 1000               | 8                      |
| Mengxi-Tianjin     | 1000               | 6                      |
| “North half ring” of East China UHV | 1000               | 6                      |

2.2. The current situation and study of UHVDC transmission technology

According to number of converter station, HVDC transmission technology can be divided into two terminals and multi-terminal HVDC transmission technology[8]. Two terminals DC transmission technology includes LCC-HVDC, VSC-HVDC and Hybrid-HVDC. The computation process is in the midst of the converter stage by which turn-off device is used. LCC-HVDC technology is quite mature now[9], which has been applied to UHVDC project from Jinjing to Sunan(as shown in Table 2). VSC-HVDC technology has independent control ability of active/reactive power without filtering devices and reactive power compensation equipment in comparison. It also can supply power to passive load without changing voltage polarity when power flow turns out[10-12]. The combination of LCC-HVDC and VSC-HVDC is Hybrid-HVDC technology that retains advantages of above two technologies.

Table 2. UHVDC projects of SGCC (until 2016)

| DC projects | Voltage levels | Transmission capacity | Sending-end  | Receiving-end |
|-------------|----------------|-----------------------|--------------|---------------|
| Fufeng      | ±800           | 6400                  |              |               |
| Jinsu       | ±800           | 7200                  | Southwest    | East China    |
| Binjin      | ±800           | 8000                  |              |               |
| Tianzhong   | ±800           | 8000                  | Northwest    | Central China |
| Lingshao    | ±800           | 8000                  | NorthEast    | East China    |

Multi-Terminal HVDC transmission is the primary stage in the development of DC power grid, made up of three or more converter stations, in the form of series, and or multi connection of DC transmission system, which has functions of multi-power supplying and multi-drop points receiving[13]. The topological network structures contain series connection, series-parallel connection, radial parallel connection, and ring network parallel connection. The working principle of series and parallel converter station are different. The former runs same DC current and changes DC voltage of converter stations to realize power allocation. However the latter, which was widely applied to project because of many advantages like small line loss and so on, runs same DC voltage and changes DC
current of converter stations to realize power allocation. Above all advantages are gathered by hybrid type, which is flexible.

Most of conventional HVDC project are two-terminal DC transmission system because of complex control and protection of multi-terminal DC transmission system. So far, there are five multi-terminal conventional HVDC projects in the world, and China has only one multi-terminal flexible HVDC project which is building now.

2.3. *The comparison between UHV AC and DC Transmission Technology's characteristic*

Table 3 lists some main characteristics of UHVAC/DC transmission technology.

| Table 3. The Characteristics of UHVAC/DC Transmission Technology |
|---------------------------------------------------------------|
| **UHVAC Transmission Technology** | **UHVDC Transmission Technology** |
| Large capacity, wide coverage, low power loss, less transmission corridors, it’s applicable for places of short distance and large capacity power transmission[14] | Large capacity, high voltage level, narrow transmission corridors, it’s applicable for places of large power and long distance power transmission[15] |
| Having drop points, networking function, it can construct UHVAC power transmission backbone network on the basis of actual requirement | Point to point, no drop points, network structure clear, it transfer power to load center without synchronized running between power grids |
| With transporting power changing, reactive power of sending/receiving-end will change which may trigger a series of reactions, in special situation, voltage instability will happen | Blocking in DC system will bring large power impulse to two terminal power transmission systems, and damage equipment |

3. *The analysis of UHVAC/DC power grid operation characteristics*

The development of UHV transmission grid adheres to the content of AC/DC all the time in China, and making that EHVAC power grid was replaced by UHVAC power grid. It makes full use of UHV AC/DC transmission technology to achieve complementary advantages, which played important role in the practical problems of energy development in developing energy bases and electrical energy transport in remote districts. At the present, China’s hybrid UHV power grids gradually become large scale[6], but, with UHVDC transmission developing, great changes take place in running characteristics of power grid, so the mode validity of “strong DC and weak AC” was forced to rethink badly, and security of transmission grid was got attention again.

3.1. *The interaction between AC and DC, causing local failure to affect entire system*

Many engineering practices show that single-phase-to-ground fault usually happened in China’s power grids, which may triggers the commutation failure of single or multi loop and makes AC section receive enormous surge. In the serve situation, it can lead DC system to block and makes power transmission to be broken down[6].

In DC transmission system, both abnormal voltage of AC side and unusual control system of DC side may trigger commutation failure, and the probability of former was bigger, which will trigger serial commutation failure if inappropriate protection measures keep abnormal factors existing.

Large power fluctuation was caused by commutation failure. DC power fluctuation was 100 to 200 times longer than commutation failure’s existing in a few microseconds. When commutation failure happens, DC power of Power grids in sending-end can’t be exported, which briefly causes large power surplus to affect AC side; large power loss will happen in receiving-end. In addition, large reactive power will be received in duration of fault and recovery to threaten security of power system.

Large surge occurring in commutation failure was dependent on DC transmission capacity, so it has to develop AC backbone structure, which avoids trigging large flow surge. China’s power grids can withstand the fault which was commutation failure at two times in single loop UHVDC system, but consequential commutation in single/multi-loop DC system will exceed withstanding scope of
power grids. Based on following three levels, this paper will make a concrete analysis as shown in table 4.

**Table 4.** Analysis of different levels commutation failures

| Three levels | Case(or supposition) | Analysis |
|--------------|----------------------|----------|
| Many times commutation failure in single loop DC system | Single phase fault happened in 500kV transmission line of East China power grid | Commutation failure continuously happened at two times in single loop DC system of adjacent domain because of inappropriate control protection |
| One commutation failure synchronously happen in multi loop DC system of sending/receiving end | One commutation failure happened under full power operation in Fufeng, Jinshu, Binjin UHVDC project | 22GW active power loss cause large power wave happen in north-Central China system’s AC section. Badly, grid islands of nearby AC section will happen |
| Many Commutation failures happen in Multi DC system | In the serve failure condition, it may cause this computation failure | Computation failure cause sending-end instable, multi loop DC bipolar blocking, which has an effect on receiving-end |

In summary, characteristics of UHV AC/DC power grids produce interaction effects between AC/DC system. DC computation failure happens in receiving-end AC power grid, not only which causes active or reactive power surge to sending-end, but transports energy surge to sending-end through DC system, and it will do damage to stability of sending-end system under serve condition.

### 3.2. Prominent problems of hybrid AC/DC power grids security and stability

The unique properties of DC system makes its transient process complex[16], this paper will analyze its impact on the entire system from the following two aspects.

#### 3.2.1. Voltage stability

Transient voltage fluctuation caused by DC system faults affects operational condition so as to change output of reactive power compensation. In this state, it should confirm whether passive compensation device continues to provide reactive power to DC, which influenced directly exchange of reactive power between AC/DC systems, so problem of voltage stability happen.

DC system will take massive reactive power in process of failure and recovery to affect change of dynamic voltage. It shows that when computation failure of single/multi-loop DC system happen, the inverter side of former will absorb approximately 4500Mvar reactive power; the latter will be more. And when Zhenan power grid is at large receiving mode of 45% receiving proportion, AC N-1 fault of 500 kV transmission line may cause voltage instability. Above analyses indicate that dynamic reactive power supporting of receiving-end should be focused on in practical operation.

Multi-infeed DC system may has problem of lack of reactive power supporting, so regulation characteristics of voltage become deteriorating. Comparing DC system with conventional units, their reactive voltage regulating characteristics were opposite. As Figure 1 shows that DC inverter station absorbs reactive power; however, same scale conventional generator supply massive reactive power.
3.2.2. Frequency Stability. Frequency regulation ability of hybrid power grids are become declining with the result that frequency stability cannot be guaranteed. For that, two factors have a crucial effect: it’s FM (Frequency Modulation) ability of unit and moment of inertia of AC system.

With clean energy units of sending-end accessing and large-scale DC of receiving-end feeding, conventional units including thermal units were replaced, however, grid standard was only for traditional units, which decrease and have a huge effect on FM ability. It shows that proportion increasing of wind power made frequency declining and massive power loss which results in unstable frequency.

In addition to lack of clean energy primary FM ability, conventional units have the same problem. When bipolar block in DC occurs, infeed-end will lose instantaneously massive power that results in a large amount of DC power surplus of sending-end and frequency declining of receiving-end. According to relevant statistics, instantaneous power loss in East China Power Grid is about 5400MW in DC bipolar block fault of primary feeding. The frequency drops to the lowest of 49.56Hz in the recent 10 years and out-of-limit time is hundreds of seconds. During the accident duration, FM ability of East China power grid units are worse, whose 80% didn’t meet requirements, as shown in Figure 2.

![Figure 1. Comparison of reactive voltage regulation performance between DC and conventional units](image)

![Figure 2. The rate of meeting standard requirements of East China’s chief generator primary FM ability](image)

The ability of power grid resistance to active power impulse and power fluctuation is determined by moment of inertia of system. In recent years, conventional units were replaced by clean energy units and large-scale DC feeding. It’s widely known that clean energy units and DC doesn’t have characteristic of moment of inertia that will directly decrease frequency regulation ability.

4. Research on measures of hybrid UHV power grids related problems

4.1. Promoting AC/DC transmission technology
4.1.1. Commutation technology. Capacitor commutation HVDC (CCC) and VSC-HVDC is paid more attention now. Conventional LCC converter technology has already been mature, and a large number of cases show that it’s suitable for the transmission projects which are large-capacity, high-voltage and long-distance. However, it needs large compensation of reactive power in sending/receiving-end. With transmission capacity increasing, reactive power balance problem of sending/receiving-end is emerging onto the surface, so commutation fault of multiple DC in sending-end region will have a great effect on stability of this power grid. CCC was developing from conventional LCC, it makes fixed capacitor accessing traditional system in type of series connection to compensate reactive power to improve stability of AC/DC system. Although effect of this technology is obvious, its low technical efficiency is learnt from comparison between equipment costs increasing and unit reactive power compensation and capacity cost declining. Therefore, it should promote AC/DC technical development based on existing technology to guarantee security and stability of UHV hybrid system.

4.1.2. Online safety analysis technology. The safe operation of power grid needs advanced dispatching mode, and online safety analysis is the key technology support of real-time dispatching turning to analytic and active type. The current online security analysis technology has many disadvantages, like poor real-time, weak adaptation and faulty automatic positioning function etc. On this basis, it should use advanced technology to establish a set of online security analysis system, as shown in Figure 3.

4.2. Paying attention to the construction of backbone structure

The scale and intensity of AC power grid can’t meet requirements of large-scale DC operation, and the security and stability of AC/DC power grid is always threatened. Scale of AC power grid should be expanded to withstand flow impulse caused by DC pole blocking of sending-end, meanwhile, it should strengthen the intensity of AC power grid to protecting from bad effects of DC fault.

The main goal of strong smart grid is to build strong and reliable physical structure to realize comprehensive optimization of power grid. Especially AC power grid must be matched with capacity and scale of DC to ensure safe and reliable operation. At the present, China is planning the pattern of east/west UHV synchronous power grid, as shown in Figure 4.
4.3. Promoting performance of clean energy related to grids

It should study and make standard of accessing grids of clean energy units, developing ability of dynamic reactive and active power regulation of clean energy station, increasing participation of power grid FM and voltage controlling process, protecting power grid from the damage caused by chain reaction of clean energy off-network on a large scale.

4.4. Taking measures for the problem of voltage and frequency stability

It’s necessary to develop and take reasonable control measures as soon as possible because of high voltage level and wide range influence of UHV transmission[5]. According to distribution of energy resources, it should plan pattern of UHV power grid, speeding up construction of backbone structure, deploying distribution of emergency electric source and improving withstanding ability of power grid to deal with fault. To facilitate monitoring of power grid operation, online monitoring system should be set up to improve the static/dynamic evaluation system. The ability of reactive power support of multi-infeed DC system should be strengthened, and it also should carry out research work of installation of dynamic reactive power compensation device for region of weak voltage stability.

It’s urgent to promote ability of primary FM, to strengthen and perfect evaluation system of its performance, and to focus on working condition. Speeding up building of pumped storage power station is for fault of UHVDC feeding, meanwhile, meeting accessing requirements of clean energy.

5. Conclusion

UHV AC/DC hybrid power grids comply with requirements of social rapid development, which are completely in conformity with distribution of energy resources in China. It can promote construction of strong UHV power grids, making UHVAC as a link and using UHVDC to realize cross-regional and long distance transmission of clean energy to provide support for global energy interconnection.

AC/DC power grid should be developed at the same time and kept both have same scale and intensity to change situation of "strong DC and weak AC". UHV AC/DC hybrid power grids in China have begun to take shape. Which continuous changing of power grid operation characteristics and emergence of new problems test ability of power grid. Under background of "the 13th Five-Year Plan", it promotes construction of UHV project and forms pattern of large-scale UHV transmission. When greatly improving capability of optimal allocation of power grid resource, operation characteristics become more complex, and interaction and effect between AC/DC power grids become deep. Probability of new problems emergence has greatly increased, so it should make continuously great innovation of corollary equipment and key technology in field of UHV transmission in the future.

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