Analysis of impact of “strong DC and weak AC” on receiving-end power system

Qiang Wang, Tianran Li and Pengcheng Yang
1 Nanjing Normal University, Nanjing, 210042, China
2 wangqiang_love@hotmail.com

Abstract. The rapid development of UHVDC transmission project has brought abundant power supply to the receiving-end power system area, but also many security and stability problems. This paper summarizes four elements that affect the strength of AC system, and then simulates the most basic two-terminal single-pole UHV transmission system by MATLAB/Simulink. It analyses the impact of receiving-end AC power system strength on real-time power, frequency and voltage. Finally, in view of operation risk of "strong DC and weak AC", this paper puts forward three countermeasures.

1. Introduction
Obviously, primary energy and load demand in China are in reverse distribution. In order to meet the urgent needs of clean energy delivery, load center power supply, energy saving and so on, China State Grid is vigorously developing the UHV AC/DC hybrid technology that suitable for long distance and large capacity transmission [1]. By the end of 2016, the goal of “six cross, five straight” has achieved in the operation scale of China’s UHV transmission, making China the only country in the world that runs UHV AC and DC, UHV AC/DC hybrid project and able to deliver cross-regional power in large scale. During the period of “13th Five-Year plan”, UHV technology accelerates into a fast tract of development, the State Grid (exclude Southern Power Grid) will form a special pattern that “three sending (northwest, northeast, southwest), one terminal (north, central, and east of China)”. Some special features, such as parallel operation of AC and DC transmission and multiple DC infeed of receiving-end power system, will emerge at the appointed time. Also, with the rapid development of UHV AC/DC hybrid transmission technology, especially the step up-grade of the scale of UHV DC transmission, great changes are taken in the operating characteristics of power grid, and the characteristic of “strong DC and weak AC” is becoming increasingly prominent [2], that is the decreasing of system dynamic reactive power support capacity and the equivalent moment of inertia. A series of new challenges emerge in the operation of power grid.

This paper take the most basic two-terminal single-pole UHV AC/DC hybrid transmission system as an example. Under the rating condition, the change of the DC transmission capacity and level of frequency and voltage in receiving-end AC power system are illustrated in the paper by changing the short-circuit capacity of receiving-end AC power system, and gets the impact of “strong DC and weak AC” at power grid stability. Also, conclusions are verified in this paper by the simulation of the system with MATLAB/Simulink.

2. Analysis of the strength of AC system
The strength of receiving-end AC power grid of UHV AC/DC hybrid transmission system is mainly
characterized by short circuit ratio (SCR). SCR reflects the influence of the strength of the external contact channel of the AC system and its own power grid structure on the stable operation of the system. Taking the traditional two-terminal UHV AC/DC hybrid transmission system as an example, the larger the SCR is, the less the voltage of converter bus decreases when the AC side is disturbed, and the slightly weaker the stability of the whole system will be influenced. SCR is defined as:

\[ SCR = \frac{S_{SC}}{P_{dN}} = \frac{1}{Z_{pu}} \]  

Where, \( S_{SC} \) is the short circuit capacity at inverter bus, \( P_{dN} \) is the rating capacity of UHV AC/DC hybrid transmission system. When \( S_{SC} \) and \( P_{dN} \) are in per unit, SCR is just the reciprocal of Thevenin reactance, \( Z_{pu} \), at inverter bus.

Therefore, under the rated operation of DC transmission line, the short-circuit capacity of receiving-end AC power system determines the system strength. A high short circuit capacity corresponds to a low equivalent reactance, which means a strong ac system; and a low short circuit capacity means a weak one [3]. The short-circuit capacity of receiving-end AC power system is affected by four factors as followed:

1) AC system operation modes. Ac system operates in numerous modes varying at every second to meet the changing energy demands. Table 1 lists the SCR of a ±500kV HVDC transmission system with capacity of 3000MW at different operation modes.

| Operation Modes | SSC (MVA) | SCR |
|-----------------|-----------|-----|
| Summer Peak     | 12858     | 4.3 |
| Summer Base     | 12039     | 4.0 |
| Winter Peak     | 12076     | 4.0 |
| Winter Base     | 11376     | 3.8 |

2) Grid configuration. If electric equipment is out of service for maintenance or protection devices trigger the breaker to work immediately when a fault occurs in AC system, those all will make some change of grid configuration.

3) Load characteristics. Load in vicinity of the inverter bus may considerably effects AC system performance. Induction motor acts as a reactive power source during the AC fault. The magnetic energy stored inside it flows to the fault point, which leads to an increasing of SCR [4].

4) Reactive compensation devices. Most of the reactive power consumption of an inverter is supplied by reactive compensation devices at inverter station.

SCR provides an intuitive and easy way to approximately evaluate the strength of AC system. Commonly, system is strong when the value of SCR is greater than 5, moderate when between 3 and 5 and weak when below 3, and if the value of SCR is less than 2, the system is extremely weak [6].

3. Impact of “strong DC and weak AC” on power grid

SimPowerSystem module of MATLAB/Simulink is used in this paper to simulate the steady and transient process of fundamental UHV AC/DC hybrid transmission system. Which not only avoids the complicated transient calculation and analysis, but also provides a convenience of intuitively observing the real-time DC transmission capacity, frequency and voltage level of receiving-end AC power system. And also verifies the impact of the strength of receiving-end AC power system at power grid stability.
3.1. The problem of power fluctuation

Power fluctuation is the most common and severe problem for UHV AC/DC hybrid transmission project, and it is mainly caused by the commutation failure of converter valve in inverter station. Traditional UHV AC/DC hybrid transmission system uses thyristor, that is why commutation failure is the most typical and common faults, as the converter valve. To ensure the reliability of commutation, the receiving-end AC power system must have sufficient short circuit capacity, which means it must be strong enough. “Strong DC and weak AC” leads to the insufficient level of short-circuit current of the receiving-end AC system when faults occur.

With the centralized feeding of multi-loop and large-capacity DC power, the characteristic that “strong DC and weak AC” of power grid is becoming more and more obvious. DC transmission system are prone to failure commutation when an AC fault occurs. And huge transient energy shock caused by wide range of power flow in the network may bring about a large power fluctuation online. If the protection switch shows mal-operation or refused operation after the fault, the voltage on the receiving-end AC system will slide continually, and it will cause simultaneous commutation failures of several lines. More seriously, blocking of DC transmission will results in a large area of power cut.

Suppose that a three-phase short-circuit fault occurred at the receiving-end AC system during 1.0-1.1s. And the varying curves of DC transmission power based different strength of AC system are shown in figure 2 and figure 3. The two waveforms indicate that if AC system is strong enough (SCR = 5), short-time fault does not have a prominent impact on feeding active power, and the fluctuations disappear just in a very short time. While when the AC system is weak (SCR = 2), a transient AC failure can result in a large fluctuations in the DC transmission power, and even lead to a DC blocking. All mean obviously that the safety and stability of power transmission system are greatly influenced by the strength of receiving-end AC system.

3.2. The problem of frequency stability

Figure 1. Fundamental UHV AC/DC transmission system.

Figure 2. The impact of the fault occurs in AC system around inverter on DC transmission power (SCR = 5).

Figure 3. The impact of the fault occurs in AC system around inverter on DC transmission power (SCR = 2).
One of the greatest features of UHV AV/DC hybrid transmission project is that it can combine two unsynchronized systems. The capacity of power frequency self-regulating depends on two factors: magnitude of AC system’s rotary inertia and the frequency self-regulating ability of units.

1). Rotary inertia of AC system.

The magnitude of AC system’s rotary inertia is proportional to the capacity of the system to withstand frequency fluctuations and active power shocks. With more and more new energy units putting into the sending terminal of UHV AC/DC hybrid transmission system, capacity fed to receiving terminal becomes bigger and bigger, and lots of traditional rotating units be replaced. So, the level of equivalent rotary inertia gradually decreases and the amplitude of the fluctuation of system’s frequency increased under the same disturbance of faults. Figure 4 and figure 5 reveal the impact of different levels of equivalent rotary inertia on frequency of receiving-end AC system.

![Figure 4. Real-time varying curve of system frequency (SCR = 5).](image)

![Figure 5. Real-time varying curve of system frequency (SCR = 5).](image)

The difference in these two figures indicates that frequency’s self-regulating and recovering ability has a direct relationship with AC system’s strength (or the level of equivalent rotary inertia). If the receiving-end AC system is strong enough (SCR = 5) or the level of equivalent rotary inertia is high, frequency can quickly return to about 50Hz in 0.4s. On the contrary, if the system is weak (SCR = 2) or the level of equivalent rotary inertia is low, frequency might recovered to rated value just after 0.8s.

2). Frequency self-regulating capacity of units in AC system.

Take the case of some UHV DC/AC hybrid transmission system. 21:58 on September 19 of 2015, receiving-end AC frequency broke down, it caused an active power loss up to 4900MW and a substantial drop of system frequency to 49.56Hz. And the system took all of 240s to return to rated 50Hz with the help of dynamic Area Control Error (ACE) operation and emergency dispatch [7]. Subsequently, the analysis of online units’ data during the failure time shows that only 20% of the units’ primary frequency modulation capacity met the relevant national standards, and some of which even worked as reverse frequency regulators. Nowadays, China State Grid is vigorously developing DC transmission projects, the bigger the rated transmission capacity of DC lines is and the more centralized the infeed is, the more conventional units will be replaced. And that further increases the possibility of online unit failures and reduces the capacity of its frequency self-regulation.

3.3. The problem of voltage stability.

Along with the increase of DC transmission power, the amount of reactive power consumed by thyristor converter valve is also increasing. DC lines can only transmit active power, so the consumption of reactive power can only be obtained from AC system. And to some extent, it must affect the voltage level of AC system; most of the receiving regions of DC transmission system are prosperous in economy and complex in load characteristic, which has a certain impact on AC voltage of receiving-end system. In some common fault case, such as three-phase short circuit, in order to ensure the normal commutation of DC lines, converter valve must absorb more reactive power from AC system, which aggravates AC voltage situation around converter stations. Nowadays, with the great progress of technology on DC transmission, rated transmission capacity is increasing and receiving regions are grouped together. Problems of voltage stability are becoming increasingly serious. Figure 6 and figure 7 reveal the impact of AC fault on voltage of AC system around inverter in different strength of receiving-end AC system.
Figure 6. The impact of AC fault on voltage of AC system around inverter (SCR = 5).

Figure 7. The impact of AC fault on voltage of AC system around inverter (SCR = 2).

The difference of the two curves reveals that both of the drop level and the time of AC voltage around inverter restoring to its rated value are inversely proportional to the system strength. If receiving-end AC system is strong enough (SCR = 5), AC voltage around inverter drops to about 0.8(p.u.) at the moment of fault and it restores to rated value in 1.4s after the removal of fault. If the system is weak (SCR = 2), the voltage drops to about 0.5(p.u.) and restores to its rated value in 1.7s.

4. Countermeasures

The arch-criminal of safety and stability problems on UHV DC/AC hybrid transmission system is multi-loop, large-capacity and centralized-feeding DC power. The stop of some traditional rotary units and the passive change of AC grid structure decrease the strength of receiving-end AC system, so do the support capacity of dynamic reactive power and the equivalent moment of inertia. According to definition and influencing factors of short-circuit ratio (SCR), there are three main measures:

1) Strengthening operation capability of peak shaving and valley filling.

Electric power peak shaving and valley filling have always been one of the important goals pursued by power enterprises. On the one hand, it can flats load curve and alleviates real-time load pressure; on the other hand it also has a great contribution to reasonable switching of electrical equipment and reduces lots of un-necessary investment. Besides, it can effectively improve the strength of receiving-end system and enhance its security and stability.

TOU power price based on DSM(Demand Side Management) and electric power storage are the traditional methods for power peak shaving and valley filling in China. With the emergence of the concept of global energy Internet and the improvement of power market system, a new way has come into being, regional electricity trade and cooperation. and benefits of electricity trade and cooperation in the Sino Russian, Sino Vietnamese and Mekong verify the correctness of this new approach. When the disparity of load between different seasons and different period of one day is sharp, it takes the conventional methods to shave peak and fill valley of load; while there are some load surplus and shortage in neighboring regions, it must appropriately manage those load though electricity trade and cooperation in time to shave peak and fill valley of load. By strengthening the operation ability of peak shaving and valley filling, operation environment of power network is optimized continuously, and the safety and reliability of network operation are improved.

2) Focusing on the construction of receiving-end AC power grid.

The practice of UHV DC/AC hybrid transmission project shows that in order to withstand the frequency shock caused by large capacity DC blocking, the AC grid scale must match the DC capacity; in order to withstand the great power impulse and voltage fluctuation caused by DC commutation failure, the strength of AC grid must reach a certain level[8]. However, with the rapid development of HVDC transmission technology, the construction of AC grid is deficient and the scale and strength of the existing AC grid is not competent to support the operation of large-scale DC grid.

During the “13th Five-Year”, the key to solve the problem of “strong DC and weak AC” is to strengthen the construction of power grid and realize the goal of “strong DC and strong AC”. Nowadays, China State Grid is actively building strong East and West power grid, which will provides a good service for the national development strategy of clean energy while optimizing and upgrading.

3) Optimizing load characteristics by synchronous condenser.
According to long-term operation tests, converter stations consume a great deal of reactive power which accounts for about 40%-60% of the rated DC transmission power, and all of those power comes from the receiving-end AC system [9]. Synchronous condenser is a kind of special synchronous motor with no prime mover which runs on light loading. It is also a special reactive power load or reactive power supply for synchronous condenser can only absorb or generate reactive power [10]. When improving the system equivalent moment of inertia, the input of synchronous condenser is of great significance to the support of reactive power.

At present, China State Grid Corporation has planned to install two 300MVar synchronous condenser in Taizhou converter station of Ximeng-Taizhou UHV project and Xiangtan converter station of Jiuquan-Hunan UHV project respectively, expecting to effectively improve the dynamic voltage stability margin of power grid, and to ensure the safe and stable operation of UHV projects [11].

5. Conclusions
The safety and stability of power grid is facing great challenges when the characteristic of “strong DC and weak AC” is becoming increasingly prominent. The simulation of the most basic two-terminal single-pole UHV transmission system realized by MATLAB/Simulink shows that: under the background of “strong DC and weak AC”, the strength of receiving-end AC system has a direct influence on the transmission power of DC lines, the stability of frequency and the fluctuation of voltage on AC system. Combined with the background of “strong DC and weak AC” and the four influencing factors of SCR who are directly related to the strength of the receiving-end AC system, three countermeasures are put forward in this paper including strengthening the operation control capability of peak shaving and valley filling, focusing on the construction of receiving-end AC power grid, and optimizing the load characteristics of receiving-end AC power system by synchronous condenser. Synchronous condenser can not only optimize the load characteristics, but also improve the strength of receiving-end AC. So it can greatly improve the safety and stability of UHV DC/AC hybrid transmission. However, both of domestic and international researches on the application of synchronous condensers in UHV DC/AC are still in their infancy, more simulation data and practical experience need dong to support its advantages. In the future, the application of synchronous condenser in UHV DC/AC hybrid transmission is the focus research.

References
[1] Zhenya Liu. Innovation of UHVAC Transmission Technology in China. Power System technology, 2013, 37(3): 566-74
[2] Qin Qin, Qiang Guo, Qinyong Zhou and Xiaohui Qin. The Security and Stability of Power Grids in 13th Five-Year Planning and Countermeasures. Electric Power, 2015, 489(1): 25-32
[3] C.W. Taylor. Power System Voltage Stability. New York: McGrawHill, January 1994
[4] Z. Y. Liu, J. Wen, M. X. Han, L. Dong and H. Ding. Researches on the load representation of Hunan power grid AC/DC system. International Conference on Power System Technology, 2007: 1-5
[5] Yuhong Wang and Xingyuan Li. Impact of AC System Strength on Commutation Failure at HVDC Inverter Station. Asia-pacific Power & Energy Engineering Conference, 2012, 59(5): 1-4
[6] Zhaowei Li, Haibao Zhai, Fusuo Liu, Zhihong Huang, Xiaodan Cui and Wei Liu. DC access capability study for multi-infeed HVDC power transmission system. Power System Protection and Control, 2016, 44(8): 142-48
[7] Zhaowei Li, Xuelian Wu and Kanqin Zhuang. Analysis and Reflection on Frequency Characteristics of East China Grid After Bipolar Locking of “9.19” Jinping Sunan DC Transmission Line. Automation of Electric Power Systems, 2017, 41(7): 149-55
[8] Mingjie LI. Characteristic Analysis and Operational Control of Large-Scale Hybrid UHV AC/DC Power Grids. Power System Technology, 2016, 40(4): 985-91
[9] Ting Cui and Yangwu Shen and Bin Zhang. Influences of 300 MVar synchronous condensers on
the stabilities of Hunan power grid. *Hunan Electric Power*, 2016, 36(3): 1-8

[10] Yating Wang, Yichi Zhang and Qinyong Zhou. Study on Application of New Generation Large Capacity Synchronous Condenser in Power Grid. *Power System Technology*, 2017, 41(1): 22-28

[11] Why do we install synchronous condensers in the hybrid power grid that has the characteristic of “Strong DC and weak AC” http://shupeidian.bjx.com.cn/html/20160809/760061.shtml