Journal of Physics: Conference Series

Research on SVG Electromagnetic Transient Simulation Technology of Large-scale Offshore Wind Power Base

Research on SVG Electromagnetic Transient Simulation Technology of Large-scale Offshore Wind Power Base

Liping Gao[1,*], Guanghui Li[1], Xin He[2], Chong Shao[2], Yanxia Sun[1], Xing Zhang[1] and Keke Liu[1]

[1]State Key Laboratory of Operation and Control of Renewable Energy & Storage Systems (China Electric Power Research Institute), Haidian District, Beijing 100192, China
[2]State Grid Gansu Electric Power Company, Lanzhou City, Gansu Province, 730050, China

*Corresponding author email: gaoliping@epri.sgcc.com.cn

Abstract. Based on the control hardware in-loop simulation technique, the article built the SVG control hardware in-loop electromagnetic transient real-time simulation platform, and completed the simulation analysis of the transient reactive response characteristics of the SVG controller under the ideal grid. Relying on the SVG control hardware in-loop simulation platform, using code encapsulation cryptography, a pure digital model of the SVG control system dynamic link library was established. The feasibility of the SVG control hardware in-loop real-time simulation platform and DLL model was verified by "three-line check" of the control hardware in-loop simulation model - DLL model - field experimental data curve, which provides a simulation analysis solution for the analysis of SVG transient response characteristics of large-scale offshore wind bases.
Keywords: Wind power base; SVG; Electromagnetic transient simulation; Control hardware in the loop; Dynamic link library model; Model check.

1. Introduction
With the rapid expansion of offshore wind power investment and construction in China, the large-scale offshore wind power transmission has become increasingly challenged. Since the voltage regulation characteristics of offshore wind turbines and reactive power compensation devices are complex, scattered and hard to control coordinately, the power grid in large-scale offshore wind power bases has poor adaptability and weaktransmission capabilities. As a result, improving the stability of the sending-end system are important tasks for the development of offshore wind power by researching the transient response characteristics of reactive powercompensation devices and proposing optimized control strategies[1-3].
In view of the advanced technology, the current reactive power compensation devices in the AC convergence stations of offshore wind power base are mainly static var generators (SVG), which play an important role in increasing the power delivery and the power factor of the grid, and suppressing system harmonics. Due to the high voltage level and large compensation capacity of SVG application, it is impossible to conduct a large number of experiments and multi-service tests in the field, therefore, the accurate semi-physical real-time simulation method is an efficient, economical and safe method. In this paper, we will build a SVG reactive compensation device simulation platform based on Controller Hardware In the Loop (CHIL) and code-packaged encryption technology to simulate various working

Journal of Physics: Conference Series **1624** (2020) 022062 doi:10.1088/1742-6596/1624/2/022062

conditions in the actual field, and complete the research and exploration of the transient response characteristics of the SVG controller[4,5].

2. SVG-CHIL Simulation Platform Construction

CHIL simulation is a typical semi-realistic simulation technique that combines the real device (controller) and the virtual platform environment. The CHIL simulation platform replaces the real device or environment other than the controller with a simulation model, and connects the simulation model to the real controller through the corresponding interface device to form a closed-loop test system, and requires the system software environment and hardware devices to run according to the time scale of the actual project, so as to complete the simulation of the whole system under different operating conditions, as well as the experimental verification of the functions and control strategies of the real controller[6,7].

As shown in Figure 1, the CHIL simulation platform is mainly composed of three parts: the digital model of the simulation platform, the actual device (controller) access, the interface design between the simulator and the actual device.

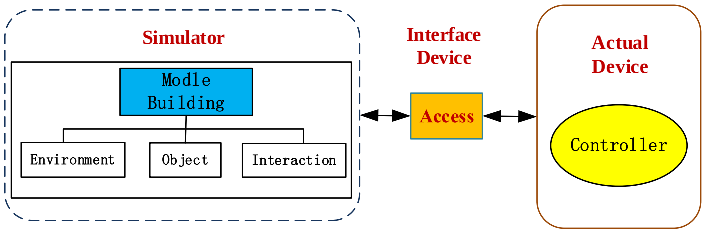


Figure 1. Principle diagram of the CHIL simulation platform.

SVG reactive power compensation devices generally use a double closed-loop control structure of voltage outer ring and current inner ring. Among them, the voltage outer ring is used to control the DC voltage Udc of the reactive power compensation device, and the current inner ring realizes the reactive current Isvg output of the reactive power compensation device. Usually the SVG control mode is divided into constant power mode, constant voltage mode, constant current mode, constant power factor and other modes according to the demand[8-10]. This paper introduces the CHIL-based SVG transient reactive power simulation platform based on the 35kV direct-mounted SVG access to 110kV transmission end grid. As shown in Figure 2, the main circuit topology of the 35kV direct-mounted SVG is composed of multiple IGBT rectifier modules in series to form a multi-level reactive power unit, connected to the device impedance L and charging resistor R, and connected to the 110kV grid through the step-up transformer, the SVG device detects the grid voltage and current on the compensation side (35kV or 110kV side), and the control device emits or absorbs reactive power to complete the reactive power compensation function. The significance of the parameters in the figure and the method of determination are as follows.

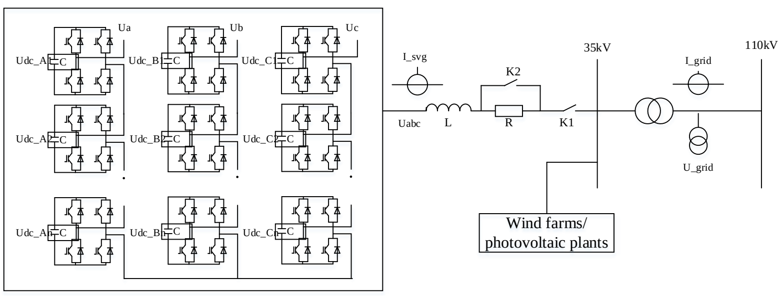


Figure 2. Main circuit topology diagram of SVG.

(1) Filter reactor L selection

Determine system impedance by considering SVG reactive power compensation device capacity and voltage class.

$$Z_N = \frac{U_N^2}{S_N} \tag{1}$$

According to the empirical value, the short-circuit impedance of the SVG device is generally 10%, so the filter reactance is.

$$L = \frac{0.1Z_N}{\omega_N} = \frac{0.1U_N^2}{\omega_N S_N} \tag{2}$$

S_N is the device capacity, U_N is AC line voltage rated value, in this case U_N is 35kV, ω_N is the operating frequency.
(2) Power module voltage U_{dc}
The power module is converted to AC line voltage with the following relationship

$$U_{m\_N} = U_{dc\_n} \times \frac{\sqrt{3}}{\sqrt{2}} \times M = 1.22M \cdot U_{dc\_n} \tag{3}$$

Where U_{m_N} is the effective value of the DC voltage equivalence of a single power module to the AC line voltage, U_{dc_n} is the nominal voltage of the DC capacitor of a single power module, and M is the modulation ratio.
(3) Calculation of the number of power modules n
Considering the system redundancy requirements, assuming a redundancy factor of k, the number of power modules is

$$n = \frac{U_N}{k \cdot U_{m\_N}} = \frac{U_N}{1.22k \cdot M \cdot U_{dc\_n}} \tag{4}$$

(4) SVG AC port equivalent switching frequency

$$f = n \cdot f_k \tag{5}$$

Where, f_k is the power module switching frequency.
(5) Number of SVG AC port line voltage equivalent levels

$$2n+1 \tag{6}$$

According to the above calculation results, the SVG circuit topology is modeled and model parameters are calibrated, and the CHIL simulation test is downloaded to the platform simulator. As shown in Figure 3, the SVG-CHIL simulation platform consists of a test management workstation, a real-time simulator, an optical interface converter and an SVG controller. The functional modules of the simulation platform are described as follows.
(1) The test management workstation is a test host, which implements functions such as model development, test management, automated testing and graphic monitoring.
(2) The real-time simulator includes an OP5600 (CPU) real-time simulator and an OP5607 (FPGA) simulator, with mathematical model real-time operation and real-time I/O port configuration and other functions, the circuit topology model in Figure 2 is finally downloaded to the simulator through the workstation to run. In this simulation scheme, the OP5600 simulator mainly runs the SVG simulation system model, the simulation step is set at 10us-50us, the OP5607 simulator is responsible for configuring the simulation interface and fiber optic communication, the simulation step is not greater than 1us, complete the real-time data interaction with the controller, the above OP5600 and OP5607 simulator through the PCIe bus for connection.
(3) Because the SVG controller has a large number of fiber-optic valve control interface can not complete the data interaction through the ordinary I/O interface, therefore, this article uses an intelligent fiber-optic interface box to complete the communication between the SVG valve control device and the simulation platform. It converts a large number (several hundred) of low-speed optical fibers of the SVG

valve control device into a small number (usually 1 to 3 pairs) of high-speed optical fiber access simulators through the communication protocol analysis and recompilation, completing the data transmission of power module capacitive voltage, IGBT trigger signals and fault flags, and so all.

(4) SVG controller is a physical device, its main control device and simulator connection to complete the acquisition of analog and digital volume, the valve control device and the fiber-optic interface converter connection to complete the fiber-optic data communication.

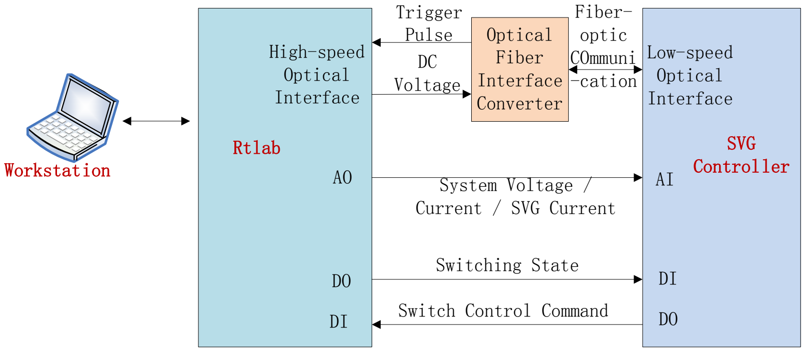


Figure 3. Schematic diagram of SVG-CHIL simulation platform.

The above-mentioned simulation platform can conduct overall testing of the SVG controller's functions and performance, verify the existing software control algorithms, control strategies, device performance, response characteristics under abnormal working conditions and other functions of the SVG controller, and timely find the controller's problems and improve the controller's logic and algorithms.

3. Real-time Simulation Analysis of SVG Transient Reactive Response Characteristics under an Ideal Grid

Figure 4 shows the circuit topology of the new energy cluster sending system under the ideal grid, in which U_N is the grid voltage of the new energy power plant, U_1 is the ideal grid voltage of the new energy base sending system, and R and jX are the equivalent impedance of the system line.

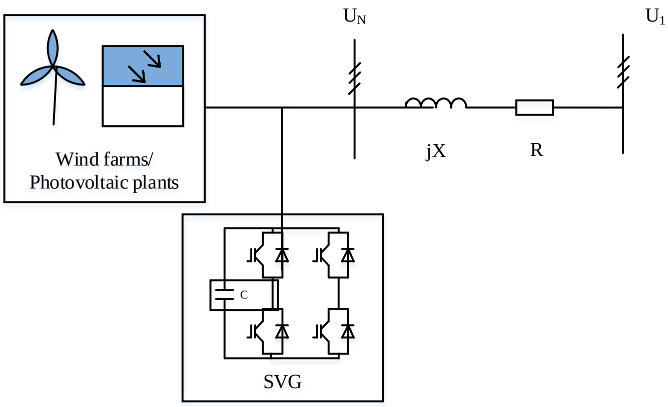
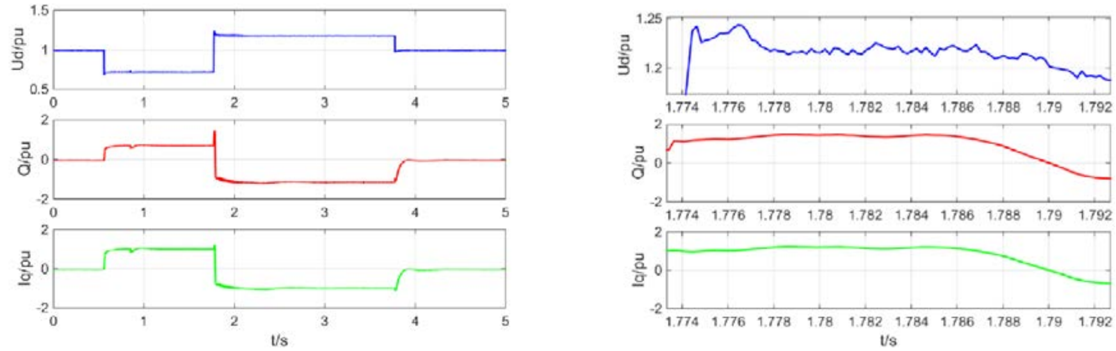


Figure 4. New energy sending system circuit topology.

When verifying the control performance and control strategy of the control device of a new energy field station, the general perturbation experiments on the grid voltage U_1 include high voltage crossing, low voltage crossing and phase change failure to monitor whether the control device can work effectively in the above three perturbation experiments[11-13]. The following SVG-CHIL real-time simulation platform is used to analyze the response characteristics of a certain type of SVG controller, set the SVG as a constant voltage control mode, complete the SVG electromagnetic transient characteristics test through four sets of SVG high and low voltage crossing and phase change failure test, and record the 35kV grid voltage U_d, reactive power Q and SVG device current.

Figure 5 is the transient response curve of SVG in the grid voltage drop from normal value to 0.7p.u. and then rise from 0.7p.u. to 1.2p.u. As can be seen from the figure: the grid voltage drop from normal value to 0.7p.u. lasting 1.214s, the low voltage crossing response time of SVG controller is 3ms, the system voltage rise from 0.7p.u. to 1.2p.u. lasting 2s, the high voltage crossing response time of SVG controller is 16ms, the maximum value of grid voltage overshoot is 0.04p.u.

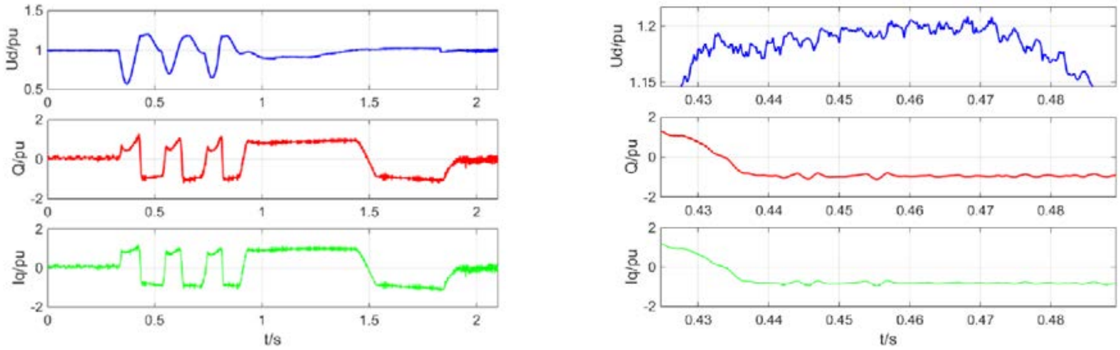


a)voltage crossing process b)high voltage crossing overshoot detail

Figure 5. High voltage crossing and low voltage crossing transient characteristic curves.

In addition, Figure 6 shows the transient response curve of SVG under a phase transition failure, which is a typical DC short fault at the receiving end of a new energy grid.

The SVG transient characteristics response curve from Figure 5 to Figure 8 can also be learned, when the system voltage is lower than 0.9p.u., SVG into the reactive full-energy open-loop control mode, the response speed is very fast, basically within a few MS to complete the low-voltage crossing process; due to the device on the grid voltage component Ud to take a high voltage crossing filter control, the response speed is slower, the general response time in an operating frequency cycle. At the same time, it can be seen that SVG can not mutate the reactive current during the high voltage crossing, which will instantly raise the system grid voltage and aggravate the high voltage crossing characteristics of the system. It can be seen that the SVG-CHIL simulation platform is used to analyze the control characteristics of SVG, which can flexibly and conveniently simulate various working conditions and observe various electromagnetic transient processes of the controller.



a)voltage crossing process of phase change failure b)high voltage crossing overshoot detail of phase change failure

Figure 6. Commutation failure transient characteristic curve.

4. Dynamic Link Library Modeling and Model Checking

In general, purely numerical modelling of a wind farm is completely feasible with a set of SVG-CHIL real-time simulations. However, if a large-scale offshore wind farm is involved, such as a new energy simulation that is made up of multiple wind farms, it is unrealistic to use the SVG-CHIL simulation scheme, which will consume a lot of reactive power compensation device controllers and multiple simulation interface devices. At this point, the SVG-CHIL simulation model needs to be purely digitalized using code encapsulation cryptography, i.e., to build the SVG controller's dynamic link library model. This is done as follows.

First, the main work of code packaging is the SVG controller control code to modify the package to generate the library function model can be run in the OP-RT simulator, the library function model must meet the following requirements: can accurately realize the SVG control algorithm and protection functions, a variety of control modes can be selected, control parameters can be modified, the model system voltage, SVG current, power module DC voltage, PWM drive signal, the switch control state, fault state, etc. to lead to the oscilloscope, to facilitate analysis.

Second, use the controller library function source code compiled to generate the .o file, and then the .o file recompiled to generate the .a library file, and then delete the source code program, directly use the .a library file to run the model, if the model and the use of the controller library function model simulation run the same results, then the dynamic link library was established successfully, the specific generation of library file flowchart shown in Figure 7.

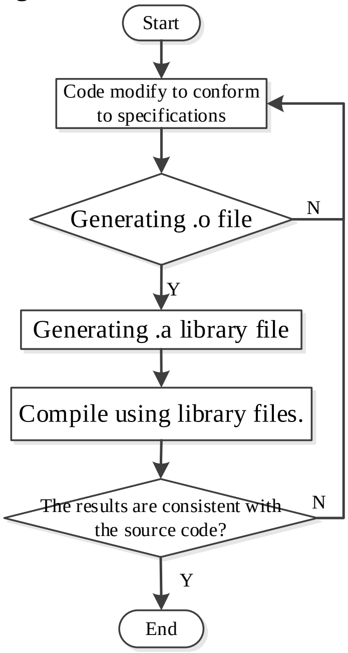
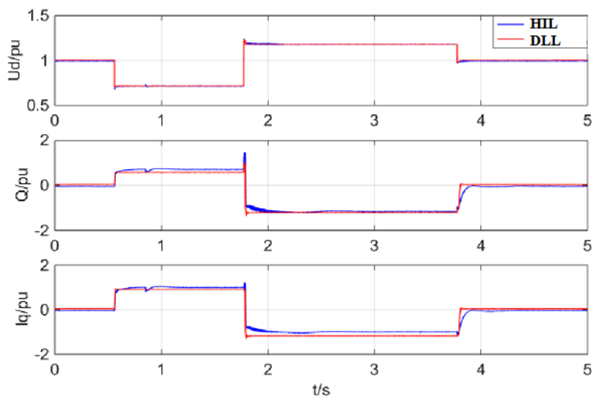


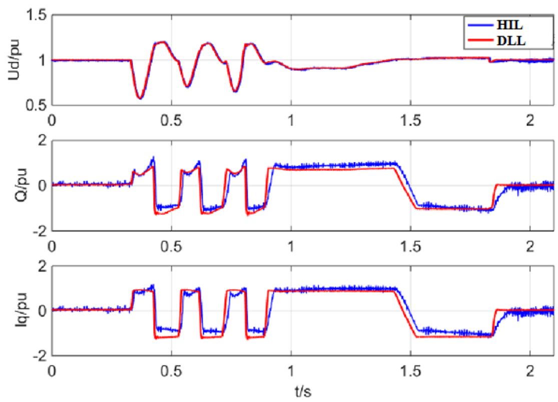
Figure 7. Generating dynamic link library file flow chart.

Finally, the DLL model is calibrated with SVG-CHIL as the benchmark to ensure the accuracy of the DLL model by relying on the SVG DLL and CHIL simulation platform. The simulation validation results are as follows.

It can be seen from Figure 8 that the SVG DLL and CHIL experimental waveforms: the SVG-CHIL real-time simulation model and the pure digital real-time simulation model based on the DLL have a high degree of accuracy. SVG's CHIL simulation model and DLL model can reflect the transient response characteristics of its controller within a small margin of error, and the accuracy of the CHIL simulation model and DLL model can meet the requirements and objectives of real-time simulation platform construction.



a)voltage crossing process



b)phase change failure

Figure 8. Comparison of SVG DLL and CHIL experimental results.

The above DLL model can reflect the controller performance to some extent, relying on the CHIL simulation model to complete the calibration, but whether the DLL model can accurately reflect the controller engineering field characteristics, requires further verification. The following electromagnetic transient modeling is carried out according to a wind power base site, and the phase change failed grid perturbation experiment is completed.

It can be seen from Figure 9 that the actual power grid perturbation experiment of SVG and the DLL simulation curve have a high degree of similarity, indicating that the CHIL simulation and DLL model can reflect the transient characteristics of the actual SVG equipment within a certain error range

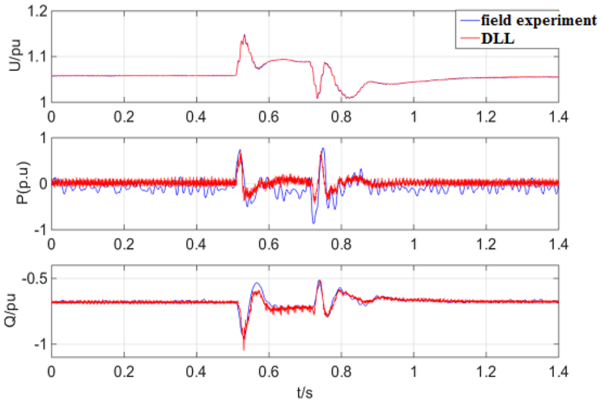


Figure 9. Comparison of SVG Dynamic Link Library and disturbing experimental results.

5. Conclusion

In summary, the SVG-CHIL simulation platform and DLL model studied in this article provide simulation and analysis tools for analyzing the transient characteristics of reactive power compensation devices in large-scale offshore wind power bases, which are conducive to grasping the transient operating characteristics of SVG in new energy bases, proposing reasonable operating control strategies for reactive power compensation devices and grid-connected equipment in new energy power generation systems, and improving the safe and stable operation level and delivery capacity of new energy grids[14]. The specific conclusions are as follows.

(1) The CHIL-based SVG transient reactive power simulation platform can accurately simulate and reproduce the transient working conditions in the field, and can simulate a variety of complex working conditions of stand-alone equipment in real time and analyze the transient characteristics of the control response of SVG.

(2) By analyzing the SVG transient reactive response characteristics of an ideal grid, it can be seen that the SVG controller will have a voltage inversion characteristic at the moment of high voltage crossing, and this characteristic will aggravate the transient overvoltage. In subsequent studies, the beneficial excesses of SVG under this condition can be accomplished by modifying control strategies, adjusting control parameters, configuring multiple types of reactive power compensation devices, etc.

(3) SVG dynamic link library using code encapsulation cryptography to complete the pure digital modeling of the SVG control system, can achieve multi-machine operation, especially suitable for large-scale offshore wind power base electromagnetic transient research with large grid capacity, high voltage level and complex regulation characteristics.

(4) The feasibility of the SVG CHIL simulation platform and the DLL model was verified by comparing the SVG-CHIL simulation curve, the DLL simulation curve and the field type test curve in several experimental waveforms under different operating conditions.

Acknowledgement

This research was supported by the Technology Project of State Grid(Research and Application of Key Technologies for Reactive Power Controling Wind Power Base under Weak Sending Terminal of UHV DC Grid, NO. NYB17201800198).

Journal of Physics: Conference Series **1624** (2020) 022062 doi:10.1088/1742-6596/1624/2/022062

References

[1] Chi, Y.N., Liang, W., Zhang, Z.K., et al. A review of key technologies for large-scale offshore wind power transmission and grid connection[J]. Chinese Journal of Electrical Engineering, 2016, 36(14):3768-3770
[2] Zhang Y.W., Sun A.M., Zhang Y.C. et al. Reactive compensation capacity configuration and optimized operation of wind farm[J]. Journal of Power Systems and Automation, 2011, 23(6):150-156
[3] Wang X.F., Wei X.F., Ning L.H., et al. Comparison of offshore wind power grid-connected and transmission schemes_Wang Xifan[J]. Chinese Journal of Electrical Engineering, 2014, 34(31):5459-5466
[4] Zhao J.C., Guan Y.G., Yan H.N. A study on the configuration and performance of reactive power devices in offshore wind turbine collector [J]. Electrotechnical, 2018, 2(2):17-26
[5] Li Y.D., Yang P., Zhou S., et al. Optimized design of reactive power compensation for offshore wind power systems[J]. Electrical Automation, 2015, 37(1):70-72
[6] Li G.H., Wang W.S., Liu C., et al. Impedance measurement of a wind turbine based on control hardware in the loop and analysis of influencing factors[J]. Chinese Journal of Electrical Engineering, 2019, 43(5):1624-1631
[7] Li G.H., Sun J., Control hardware-in-the-loop simulation for turbine impedance modeling and verification[C]. Proceedings of the 16th Wind Integration Workshop. Berlin, Germany: IEEE, 2017.
[8] Sun J., Li M.J., Zhang Z.G., et al.Renewable energy ransmission by HVDC across the continent:system challenges and opportunities[J]. CSEE Journal of Power and Energy System, 2017, 3(4):353-364
[9] Wang W.S., Shen H., A consideration method for wind farm nodes in power system tide computing[J]. Journal of North China Electric Power University, 2002, 29(Sup):150-153
[10] Wang S.S., Zhou X.N, Tang G.F., et al. Mathematical model of modular multi-level voltage source converters[J]. Chinese Journal of Electrical Engineering, 2011, 31(24):1-8.
[11] Huang F.N., Zhang H.L., Ma Q. et al. Interaction between end-grid ultra-high voltage DC system.
[12] Sun J, Wang G.N., Du X., et al. A theory for harmonics created by resonance in converter-grid systems[J].IEEE Transactions on Power Electronics, 2019, 34(4):3025-3029
[13] Tang, G.F., He, Z.Y., Pang, H., et al. Research, application and development of flexible DC power transmission engineering[J]. Power system automation, 2013, 37(15):3-14
[14] Lv J., Cai X.. Optimized design of controller parameters for improving the stability of flexible grid-connected systems in wind farms[J]. Chinese Journal of Electrical Engineering, 2018, 38(2):431-443