Study on Key Technical Schemes for Grid-connected Performance Testing of Offshore Wind Turbines

Zhenhua Lv \(^{1}\)\(^{*}\), Qiang Li \(^{1}\), Weijia Tang \(^{1}\), Huachun Han \(^{1}\) and Meng Yu \(^{1}\)

\(^{1}\) Jiangsu Electric Power Test Research Institute Co., Ltd., Nanjing, 211103, China
Email: 517480859@qq.com

Abstract. Offshore has the characteristics of not occupying land, rich in wind power resources, and has the advantages of high utilization hours of power generation and suitable for large-scale development. It has become the key direction of global wind power development. It can be predicted that offshore wind energy will become a very important part of the global energy internet in the future. After 20 years of wind power operation experience and the wind power technology improvement, the business and operation environment of offshore wind power development is becoming more and more mature. As the wind turbines installation site extends from land to offshore and deep-sea areas, "large" wind turbines have become the trend of offshore wind turbines development in the future. With the large-capacity offshore wind turbine prototype of many wind turbine manufacturers in China coming off the production line and successfully put into operation in China's coastal areas, offshore wind turbines above 6MW began to be put into commercial operation. Therefore, it is urgent to carry out relevant tests and inspections to improve the operation and grid connection performance of the unit. It is of great significance to master the operation characteristics and control methods of offshore wind turbine, qualitatively and quantitatively analyze its impact on power grid, study offshore wind power detection methods and develop relevant detection devices. Due to the differences of offshore environment, operation control and the particularity of offshore power transmission and collection mode, the onshore wind power test and detection ability cannot adapt to the new changes and requirements of offshore wind energy test and detection.

1. Introduction
Due to its high power generation utilization hours, rich resources, suitable for large-scale development and no land occupation, offshore wind energy has become the one of key direction of wind power development in the world. It is foreseeable that offshore wind power will become a very important part of the global energy in the future. After 20 years of accumulation, with wind power operation experience and the improvement of wind power technology, the commercial and operating environment for offshore wind power development has become increasingly mature. The European Union such as Denmark and Germany is the leader in the offshore wind power development, and it is also the region with the fastest and earliest development of offshore wind power. In terms of the European Wind Energy Association, offshore wind power reached 40GW in 2020, which can provide 4% of EU electricity demand. The offshore wind energy resources are very rich in China. And the development potential of offshore wind power is huge. Wind power development comprehensive plan "China Wind Power Development Roadmap 2050" reports that: by 2030, 2050, China's wind power installed capacity will be reached 400 million and 1 billion kilowatts. And will become one of five major power sources in China.
As wind turbine installation sites extend from land to offshore and deep sea areas, the "large-scale" wind turbines has become the offshore wind turbines development trend in the future. Foreign wind turbine manufacturers SIEMENS, VESTAS, Repower, GE, etc. took the lead to enter the "6.0MW" era, and VESTAS 10MW offshore wind turbines have also been already put into operation. As the large-capacity offshore wind turbine prototypes of many Chinese wind turbine manufacturers rolled off the assembly line and successfully put into actual operation in coastal areas of China, offshore wind turbines over 6MW began to be put into commercial operation. Therefore, it is urgent to carry out relevant tests and inspections to improve the operation and grid connection performance of the units. The control and operation of offshore wind energy is difficult, and the offshore meteorological conditions are complicated. It is of great significance to master the operating characteristics and control methods of offshore wind turbines, qualitatively and quantitatively analyze their impact on the power grid, study offshore wind power detection methods and develop related detection devices. Due to the differences in the offshore environment, the differences in operation control, and the particularity of the offshore transmission and collection methods, the onshore wind power test and detection capabilities cannot meet the new changes and requirements of the offshore wind energy test and detection.

2. Research Status and Progress
Due to the huge investment and harsh operating environment of offshore wind energy, the later transformation is basically impossible. At present, the offshore wind turbines of mainstream wind power manufacturers in China are in the prototype research, commissioning and trial operation stages. The verification of design parameters of wind power products, the power generation efficiency optimization, and the verification of reliability all rely on testing and testing methods. Therefore, the core and key technologies of offshore wind turbines urgently need to be tested and verified.

2.1. International
European wind power developed countries have started research on offshore wind power earlier. Various countries have successively established offshore wind power test bases for wind turbine characteristic research and testing, accumulated relevant data, and gained a certain amount of operation and maintenance experience. Among them, the main focus is on the operational characteristics and safety test detection of offshore wind turbines. There are relatively few researches on the grid-connected performance test and detection of wind turbines.

In terms of onshore wind turbine testing, developed countries such as Europe and the United States of America and other wind power began to test the grid-connected characteristics of wind turbines as early as the end of the last century, and they already have grid-connected testing capabilities [1,2]. They have formed a complete wind power standard system and established a wind power testing and research organization in national level. Such as the Danish National Renewable Energy Laboratory DTU/Riso, the NREL - Department of Energy Renewable Energy Laboratory in U.S., the German Wind Energy Research Institute DEWI, the ECN - Dutch Energy Research Center, the Greek Renewable Energy Research Center CRES and other internationally renowned wind power testing and research institutions, and has carried out many research work in the detection of wind turbines connected to the grid [3]. These research institutions are now also carrying out research work related to offshore wind power.

European wind power developed countries have carried out early testing and research on the complete machine and components related to offshore wind turbines. In 2001, Denmark conducted mechanical tests on 20 2MW offshore wind turbines for the first time in a wind farm near Copenhagen. At present, the Danish government is working with universities, research institutes, and manufacturers to carry out trials of 12MW-class large-capacity offshore wind turbines on the west coast of Denmark. In 2009, Germany's first offshore wind power test site Alpha-Ventus was officially put into operation. At present, more than 40 wind power research and testing institutions have carried out 15 test research projects here. Including hydrology, geology, meteorology, wind turbine foundation, wind turbine...
components, etc., the research results will be applied to future commercial offshore wind energy projects. The National Renewable Energy Centre (NAREC) is planning to establish a comprehensive test platform integrating grid adaptability and low-voltage ride-through. And 15MW wind turbine drive chain, 100-meter blade testing, offshore wind measurement system, and wave and seabed simulation would be established [4]. The detection of the grid-connected characteristics of offshore wind turbines abroad is still in its infancy, and there is little research on test detection technology.

2.2. National
In China, the test and detection research of wind turbines is mainly concentrated on land, and the onshore wind turbine test and detection technology has been mastered, and it has a complete test and detection capability. China's offshore wind energy research started relatively late, offshore wind turbines are in the prototype R&D stage, commissioning and trial operation. Although the mechanical characteristics and grid-connected characteristics of the units need to be gradually improved through testing and testing, offshore wind power testing and testing are still in the stage of exploratory research. China's offshore wind turbines are at the design and calculation stage, and they have not carried out power characteristic testing and field test verification and testing of mechanical loads, and it is impossible to verify the accuracy of their design parameters. The relevant standards have not yet been studied in depth, and there is still a big gap in the level compared with foreign countries [5,6].

At present, the power characteristic test and mechanical load test of onshore wind turbines are relatively mature. The Chinese wind power testing organization has participated in the preparation of IEC wind turbine power characteristics foundation for offshore wind energy testing has been laid. In recent years, with the support of science and technology projects of the Ministry of Science and Technology and the National Energy Administration, China has established a complete onshore wind power detection capability [7], and has mastered the grid-connected performance of wind turbines such as power quality, power control, grid adaptability, and low-voltage ride-through capability [8]. The inspection method has basically established a complete inspection standard system for offshore wind turbines. Offshore wind power has a strong momentum of development in China, and the detection method of the grid-connected characteristics of offshore wind turbines are in the research stage. And there is a lack of corresponding detection methods and detection standards. There is an urgent need for close cooperation between relevant research institutions and equipment manufacturers to carry out relevant research on testing technologies, establish offshore wind power testing and testing capabilities, and form relevant testing standards.

3. Requirement Analysis and Key Technology

3.1. Requirement Analysis
Early in the development of onshore wind power in China, due to the imperfect wind power standard system, a large mount number of wind turbines were connected to power grid, which exposed a large number of problems. There have been very large scaled wind energy off-grid accidents and wind curtailment and power rationing, which have adversely affected the healthy development of the industry. The offshore wind power research that has been carried out mainly focuses on the development and research of offshore wind turbines, basic unit design, project management, equipment design of wind farm construction, operation, installation, and maintenance. However, the foundation of offshore wind energy in China is still relatively weak. The offshore wind energy standard system is still many deficiencies. The research on offshore wind energy location and wind power forecasting is not in-depth. The research work of offshore wind power grid connection and testing and testing is insufficient, and the quality and performance of offshore wind power products cannot be guaranteed. However, due to the huge investment, harsh and complicated operating environment of offshore wind energy, it is very difficult to guarantee the return on investment.

Based on the development experience of onshore wind energy and the status quo of offshore wind energy development, the development of offshore wind energy needs to be planned in advance, and
the technical problems of offshore wind turbine performance and test testing need to be focused on to ensure the rapid and healthy development of offshore wind energy. China has not yet established a flexible and efficient offshore wind turbine research and development, test and inspection platform, and does not have the ability to test and test offshore wind turbines. However, due to the huge investment and harsh operating environment of offshore wind power, the later transformation is basically impossible. At present, the offshore wind turbines of mainstream wind power manufacturers in China are in the critical stage of localized R&D, commissioning and trial operation. The verification of design parameters of wind power products, the optimization of power generation efficiency and the verification of reliability all rely on test and detection methods. The core and key technologies of offshore wind turbines are in urgent need of testing and verification.

3.2. Key Technology

3.2.1. Grid Adaptability Test for Large-capacity Offshore Wind Turbines

- Study the influence of long-distance submarine cables, system equivalent impedance, equivalent reactance of wind box transformer and LC filter circuit of wind turbine converter on wind power background harmonics
- Study the resonance mechanism of the interaction of test equipment, submarine cables and wind turbines, and study the method of testing harmonic superposition to avoid harmonic resonance
- Study the test methods of voltage operation adaptability, voltage unbalance adaptability, frequency adaptability, and flicker adaptability of offshore wind turbines.

The key technology of grid adaptability test is shown in figure 1.

![Figure 1](image1.png)

**Figure 1.** Key technology of grid adaptability test.

3.2.2. Grid adaptability Large-capacity Detection Device of Offshore Wind Turbine

- Study the system structure of the grid adaptability detection device for offshore wind turbines with large-capacity
- Study topology of the power simulation unit of the large-capacity high-voltage grid disturbance generator based on low-voltage power switching devices
- Compare the advantages and disadvantages of the traditional low-voltage scheme, the three-level scheme, and the cascade chain scheme of the full-power converter

The key technology of grid adaptability detection device is shown in figure 2.
Based on the above technical difficulties, relevant research recommendations focus on three types of technical problems, as shown in Figure 3.

- First, solve the contradiction between large capacity and high integration of testing equipment, solve the problem of operation control of testing equipment, and develop testing equipment suitable for the test requirements of offshore wind turbines.
- Second, master the on-site inspection process of offshore wind turbines, formulate test plans, and carry out typical tests.
- Finally, on the basis of on-site testing, relevant testing standards are formulated to standardize the testing and testing of offshore wind turbines.

**Figure 3. Three types of technical problems**

4. Conclusion
Onshore wind power testing and testing capabilities cannot meet the requirements of offshore wind energy testing and testing, mainly in terms of testing methods and testing equipment. In terms of testing methods, the diameter of the wind turbines of offshore wind turbines is very large, and it is difficult to measure wind by traditional methods. It is very necessary to study offshore wind
measurement methods suitable for the offshore wind turbines and offshore environment. The load of offshore wind turbines is special and complex, and it is necessary to study a variety of test methods for specific offshore loads. Offshore wind power transmission and collection methods have a greater impact on the fault ride-through of wind turbines, and it is very necessary to propose elimination measures based on influencing factors. In terms of test equipment, the trend toward large-scale wind turbines makes it difficult for existing test equipment to meet capacity requirements. Marine test equipment needs to consider the requirements of the operating environment for salt spray and corrosion resistance, and the equipment has high requirements for operational stability, monitoring and automation. Really simulating the large-scale off-grid process of wind energy requires the development of large-capacity, high- and low-voltage ride-through integrated test equipment.

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