Front. Eng. Manag. 2020, 7(4): 618–621
https://doi.org/10.1007/s42524-020-0142-0

SUPER ENGINEERING

Huali HAN, Yalin LIU, Can WANG

Quality and efficiency improvement technology for five megawatt offshore wind turbines and its application

Keywords renewable energy, megawatt offshore wind turbine, technology-driven, quality improvement

1 Background

The offshore wind resources of China are widely distributed and have large regional differences. The Yellow Sea and Bohai Sea areas, which account for 60% of the developable sea area, have an annual average wind speed of less than 7.5 m/s (Xu et al., 2013). According to the current level of offshore wind power transportation, construction, and operation and maintenance, the profit balance point of 5.0 MW offshore wind turbines is 3000 h/year (Zheng, 2017). However, in the Yellow Sea and Bohai Sea areas, even if the world's best offshore wind turbines at that time are used, their full power generation hours can only reach approximately 2900 h/year. This phenomenon is on the verge of profitability or loss, resulting in a large number of sea areas, especially the Bohai Sea area, with no development value. Therefore, developing offshore wind turbines with strong power generation capacity and low cost, which is suitable for the sea areas in China, is urgently needed. Thus, the H171 5.0 MW offshore wind turbine project is introduced.

2 Project indicators

The H171 5.0 MW offshore wind turbine project is a key technological innovation achievement for the main industries in Chongqing, China. With the design of the H171 5.0 MW (3B +) offshore wind turbine (Fig. 1) completed, the project has formed a full set of design documents with independent intellectual property rights. The main technical parameters of the unit comply with the national standards. The number of blades is 3, with horizontal axis in the upwind direction, independent pitch, and active counterwind; the rated, cut-in, and cut-out wind speeds of the H171 are 9.6, 3.5, and 25 m/s, respectively; the operating temperature is −10°C to 40°C; the designed life span of the entire machine is 25 years; the lightning protection design conforms to the IEC1024-I standard; and the limit wind speed (average value within 3 s) is 59.5 m/s.

Fig. 1 H171 5.0 MW offshore wind turbine.

The H171 5.0 MW units have numerous leading technical indicators. The design and manufacturing technology of medium and low wind speed offshore wind turbines has reached the international leading level. The turbine also has significant advantages over offshore wind turbines in the same level.

(1) The swept area per kilowatt of the units is 4.59 m^2, ranking first in the world for offshore wind turbines.

(2) The units break through the profit balance point of 3000 h/year for offshore 5.0 MW wind turbines, endowing a considerable part of the Yellow Sea and Bohai Sea areas with development value.

(3) The average available utilization rate of the wind farm is 98.35%, which is higher than the 97% requirement of the industry. The equivalent full power generation hour

Received September 9, 2020

Huali HAN (✉), Yalin LIU, Can WANG
Research Institute of China Shipbuilding Group Haizhuang Wind Power Co., Ltd., Chongqing 401122, China
E-mail: hanhuali@163.com

is 3800 h at an average annual wind speed of 7.5 m/s. The units are the preferred model in the waters north of the Yangtze River Estuary.

3 Key technology and innovation

China Haizhuang Windpower developed the offshore wind turbine H171 5.0 MW based on the urgent needs of the wind power industry for the cost-effectiveness, reliability, environmental adaptability, and maintainability of offshore wind turbines. The construction of this wind turbine is also in accordance with the development and operation and maintenance experience of offshore wind turbines, the marine environment, and the characteristics of wind resources in China's sea areas. The offshore wind turbine H171 5.0 MW is expected to maintain international competitiveness in the medium- and long-terms, especially in extreme design, extreme manufacturing, and NO Bug design, keeping innovation in key technologies, and forming a new generation of novel products.

3.1 Load solutions adapted to offshore wind conditions

(1) The design of offshore wind turbines has to consider complicated boundary conditions and various types of working conditions. Determining the rationality of the system design is difficult, resulting in excessive load, heavy wind turbine structural design, and complicated manufacturing, which is uneconomical. Thus, a load extrapolation technology is proposed. This technology can use the load characteristics of the existing product line to calculate the load characteristics of the newly developed models for the evaluation of the system compatibility and load of the newly developed models (Figs. 2 and 3).

(2) A speed adaptation technology is proposed for the excessive load. The entire machine and the blades are micro-matched by appropriately adjusting the rated speed of the wind turbine. Thus, the aerodynamic efficiency and thrust of the blades below the rated wind speed are reduced, thereby decreasing the load of the entire machine, except the torque of the drive chain. This method can reduce the critical load by approximately 8% (Fig. 4(a)), while the power generation is only decreased by 0.2% (Fig. 4(b)).

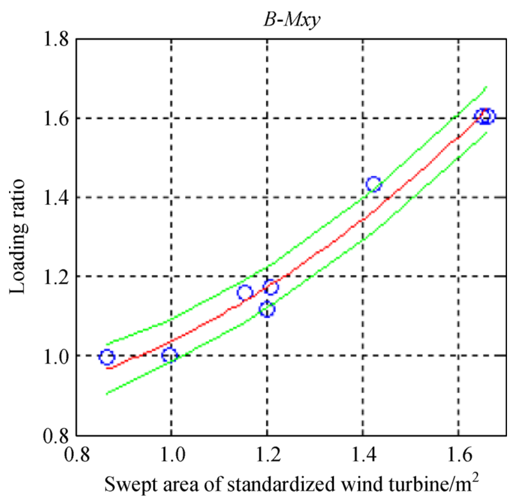

Fig. 2 Extrapolation result of blade root ultimate load.

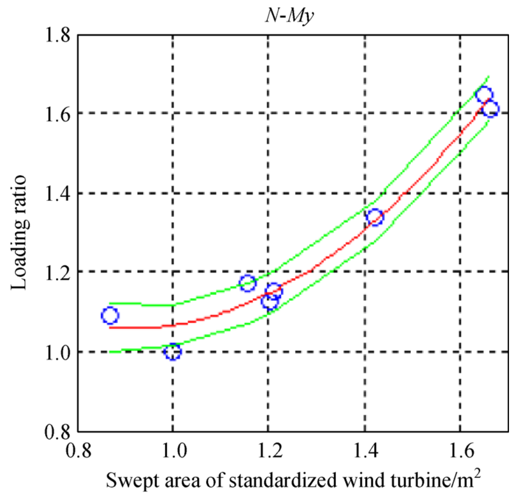

Fig. 3 Extrapolation result of frame fatigue load.

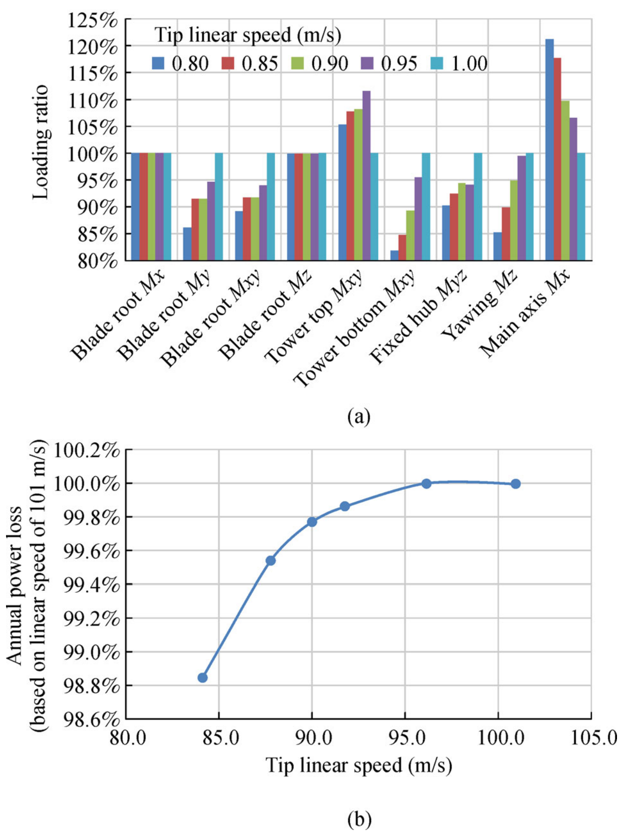

Fig. 4 Effect of reduction in blade tip linear speed (rated rotor speed) on (a) load and (b) power generation.

(3) Active pitch change can reduce the load near the rated wind speed. However, this reduction will decrease power generation. Therefore, a pre-pitch diagnosis technology is proposed to calculate the optimal pre-pitch angle, which reduces the main load by 2% to 8% but only loses 1% of power generation.

(4) The critical load is reduced by approximately 10% through load extrapolation, speed matching, and pre-pitch diagnosis and determination technologies, and most of the loads fall into a reasonable range of estimation.

3.2 Dynamic lubrication control technology for timely control of the grease injection amount of the pitch bearing based on the operating state

(1) The influence of the deformation law of the pitch bearing on the pitch drive is studied, the layout of the pitch drive is optimized, and the life span of the pitch bearing is effectively extended. The design principle of setting the pitch drive at $60° \pm 20°$ is proposed on the basis of the results of the overall finite element analysis combined with the actual operating experience of the wind farm (Fig. 5). The pitch drive is located in the area where the change in gear backlash during the pitch process can be minimized, the smoothness of transmission can be improved, and the problem of accelerated wear of meshing gear caused by the opening deformation of pitch bearing and related parts during long-term operation can be solved.

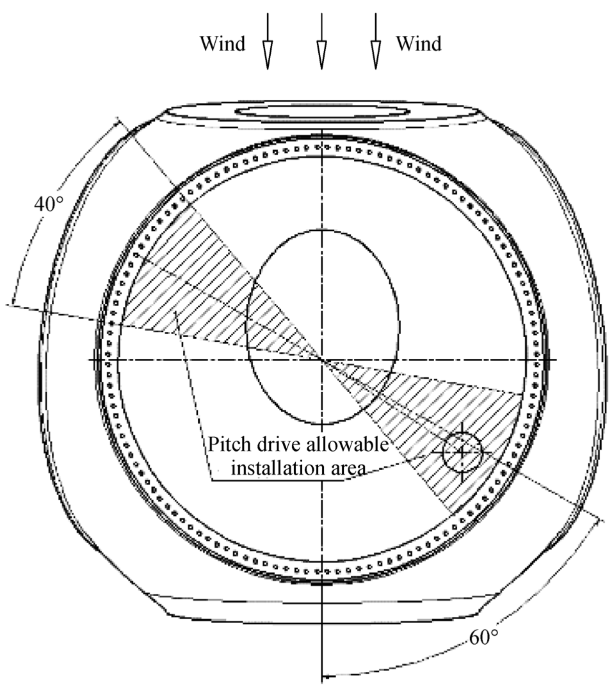

Fig. 5 Design principles of pitch drive position.

(2) The disadvantages of the traditional regular and quantitative grease injection are as follows. 1) An excessive amount of local grease is found in the bearing, which will damage the bearing sealing ring and cause grease leakage. And 2) the gear ring is unevenly lubricated; thus, the grease easily accumulates and falls. A dynamic lubrication control technology based on running state and timely control of the grease injection amount of pitch bearing is proposed to solve the problem of uneven and over lubrication of bearing and gear ring (Fig. 6).

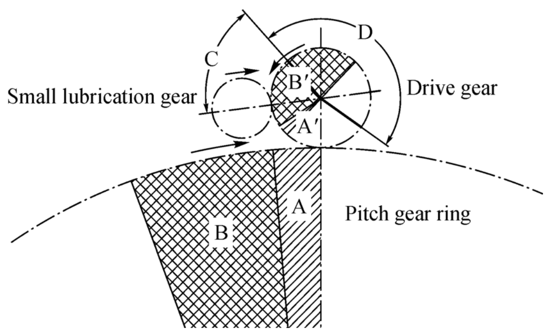

Fig. 6 Schematic of dynamic grease injection structure.

3.3 Anti-corrosion technology combining the cabin environment control of offshore wind turbines with the labyrinth seal structure

The project introduces the anti-corrosion technology, which combines the cabin environment control of offshore wind turbines with the labyrinth seal structure (Fig. 7). The cabin environment is improved and the anti-corrosion effect is achieved by controlling the salt spray concentration, humidity, temperature, and other main corrosive factors. China Haizhuang also presides over the drafting of the national standards GB/T 33630-2017 "Offshore wind turbine generator systems — Specification for corrosion protection" (General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China and Standardization Administration of China, 2017).

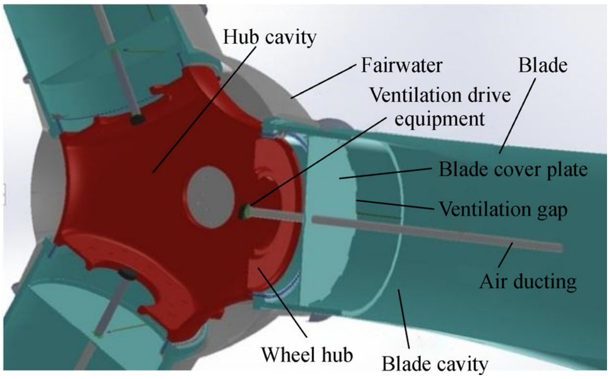

Fig. 7 Schematic of wheel hub cooling system.

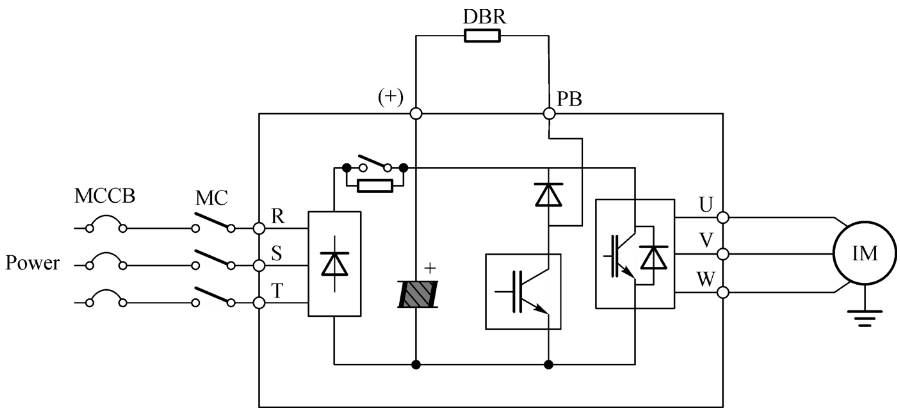

Fig. 8 Control technology of DC (direct current) bus braking unit of yaw inverter.

3.4 Simulation of the entire process of yaw system movement

The dynamic simulation technology of the yaw system, the motor inverter control technology (Fig. 8), and the motor S-curve control technology are proposed to realize the entire simulation process of the yaw system movement.

4 Application effect

The first H171 5.0 MW unit was hoisted and installed within the Huaneng Rudong Baxianjiao project on August 11, 2017 (Fig. 9), and the commissioning was completed and the grid-connected power generation was realized on September 8 in the same year. From November 2017 to July 2018, the average available utilization rate within the nine months was as high as 98.35%, which is equivalent to full-service hours of 2935 h. For the 300 MW projects, the availability rate of H171 5.0 MW single units ranks at the forefront, with the number of single-unit full-power generation hours to be highest in the field. Several statistical analyses of actual operation data concluded that the actual power generation of H171 5.0 MW units is approximately 18% higher than that of conventional units with average wind speed of 7 m/s.

Fig. 9 Huaneng Rudong Baxianjiao Offshore Wind Farm.

After the H171 5.0 MW units passed the wind farm operation inspection in 2018, it won the 2018 Best Model Award issued by the Chinese Wind Energy Association. The successful development of H171 5.0 MW units ensures China's sustainable international competitiveness in the next three to five years. This wind turbine also supports the development of the wind power market and marks the significant improvement of the research and development level of offshore high-power generators in China.

5 Outlooks

In 2020, China Haizhuang will provide H171 5.0 MW units for the Huaneng Rudong H3 offshore wind power project in batches. The project is located in the sea area of Rudong County, Jiangsu Province. The center of the site is 39 km away from the shore, with a total installed capacity of 400 MW. Among the planned 80 wind turbines "made by Haizhuang" for installation, 25 H171 5.0 MW units will be put into batch operation for the first time in the wind farm. Technology-driven high-quality development will bring additional economic benefits to owners and contribute a considerable amount of green energy to sustainable development.

References

General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China, Standardization Administration of China (2017). Offshore wind turbine generator systems—Specification for corrosion protection. GB/T 33630–2017

Xu J W, Zhang X Z, Luo Y, Xu M (2013). The validation analysis of QuikSCAT wind speed and the wind distribution in China's offshore areas. Acta Oceanologica Sinica, 35(5): 76–86 (in Chinese)

Zheng J (2017). Development direction of offshore wind turbines: The annual equivalent full-service utilization hours exceeds 3000. China Energy News (in Chinese)