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A review of offshore wind turbine nacelle: Technical challenges, and research and developmental trends

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ABSTRACT

The turbine nacelle with traditional wind power generation system is heavy, especially in offshore applications due to the large mass of the power frequency step-up-transformer operated at 50 or 60 Hz, and copper conductor generator. For example, the weight and volume of a 0.69/33 kV 2.6 MVA transformer are typically in the range of 6–8 t and 5–9 m^3, respectively. The weight for a 10 MW direct drive permanent magnet generator is about 300 t. These penalties significantly increase the tower construction, and turbine installation and maintenance costs. The tower cost represents 26% of the total component cost of the turbine and on average about 20% of the capital costs are associated with installation. Typical maintenance cost of an offshore wind turbine is about 2.3 cents/kWh, which is 20% higher than that of an onshore based turbine. As alternative approaches to achieve a compact and lightweight offshore wind turbine nacelle, different concepts have been proposed in recent years, such as step-up-transformer-less system, medium-frequency (in the range of a few kHz to MHz) power transformer-based system, multilevel and modular matrix converter-based system and superconducting generator-based system. This paper aims to review the technical challenges, current research and developmental trends, and possible future directions of the research to reduce the weight and volume of the nacelle. In addition, a comprehensive review of traditional wind power generation technologies is conducted in this article as well.

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1. Introduction

The energy and environment represent two major areas of global crises, but it is becoming more and more obvious that wind energy may offer solutions to these enormous challenges [1]. Wind energy has continued the worldwide success story as the wind power development is experiencing dramatic growth [2–6]. The cumulative growth of wind turbine installation has directly pushed the wind technology into a more competitive area [7–12]. In this propitious climate, it is therefore essential for scientists and researchers to find the most effective technologies for wind power generation systems.

Wind speed varies continuously as a function of time and height because of changes in the thermal conditions of air masses. The motion of air masses is not only a global phenomenon but also a regional and local phenomenon. The annual peak hours are normally around 2500–3000 in good sites. Wind turbine generator converts wind energy to electricity energy. It follows the energy reservation principle. If A is the cross-sectional area through which the air of velocity V flows, and ρ the air density, the theoretical power P available in a wind stream can be calculated from [13,14]

$$P=\frac{1}{2}\rho AV^3. \quad (1)$$

Usually offshore winds tend to flow at higher speeds than onshore winds. This allows the turbine to produce more electricity as the possible energy produced from the wind is proportional to the cube of the wind speed. Also unlike onshore wind, offshore breezes can be strong in the afternoon, matching the time when load demands are at peak level. Moreover, wind farms cover large areas of land. The land area covered by a 3.6 MW turbine can be almost 0.37 km^2; such that 54 turbines would cover about 20 km^2 of land area. Table 1 summarizes the land covered by some offshore wind farms [15–19]. Offshore wind farms save land rental expense which is equivalent to 10–18% of the total operating and maintenance costs of a wind farm. Therefore, offshore based wind farms have attracted significant attention in recent years. According to statistical data, the cumulative installed capacity of offshore wind farms in 2008, 2010 and 2012 was 1.50, 3.08 and 5.41 GW, respectively [20]. The capacity therefore doubled in every two years. Table 2 summarizes the global annually installed capacity of offshore wind farms. It is expected that the global offshore installed capacity will increase to approximately 20 GW by 2015 and rise sharply to 104 GW by 2025. According to the Global Wind Energy Council and Green Peace International estimations it is possible to mitigate 20% of global electricity demand with wind power [21].

Wind turbines are broadly classified into two categories: horizontal axis wind turbines and vertical axis wind turbines. The rotation of main rotor shaft of a horizontal axis wind turbine is in the direction of the wind. The rotor, generator, step-up transformer, and other equipments of a horizontal axis wind turbine are usually integrated in a nacelle placed at the top of the tower. On the other hand, the rotation of rotor shaft of a vertical axis wind turbine is perpendicular to the ground, and in a vertical axis wind turbine, the generator, transformer, converters and other equipments are usually assembled near the ground. Due to its better aerodynamic performances compared with the vertical axis wind turbines, the horizontal axis wind turbines are most commonly used in large-scale offshore wind farms. This paper mainly focuses on the horizontal axis wind turbines.

The turbine nacelle usually houses the generator, power converter, grid side step-up transformer and monitoring and control equipment. The tower provides support to the rotating parts and

Table 1
Offshore wind farms data.

Wind farms	Power capacity (MW)	Distance to shore (km)	Number of turbines	Land covered (km^2)
Barrow	108	7	30	10.00
Gunfleet Sands	172	7	48	17.50
Horns Rev	160	15	80	20.00
Horns Rev 2	200	27	91	35.00
Lynn and Inner	194	9	54	20.00
Ormonde	150	10	30	8.70
Princess Amalia	120	23	60	14.00

Table 2
Global offshore wind farms installed capacity.

Year	Annual addition (MW)	Cumulative (MW)
2002	170	256
2004	110	633
2006	93	816
2008	373	1507
2010	999	3083
2012	1293	5410

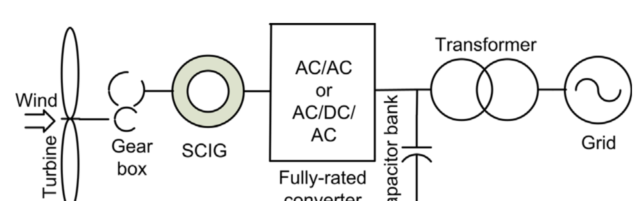

Fig. 1. Constant speed wind power generation system with SCIG.

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