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Fault analysis of wind turbines in China

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ABSTRACT

The installed capacity of wind turbines in China increased rapidly in the past 10 years. Against the backdrop of growing wind turbine capacity, the failure of wind turbines is becoming increasingly serious. Based on the three primary configurations and failure statistics analysis of wind turbines in China, this paper summarizes the failures of wind turbine components, such as frequency converters, generators, gearboxes, pitch systems, yaw systems, blades, braking systems and sub-synchronous machines. Although there are many failure types and various causes, we can deduce four primary reasons for these failures: lack of core technologies; inferior quality due to price competition; design standards and wind farm climate differences; and no mandatory quality certification and exterior factors, such as wind farm construction, power grids and maintenance. Finally, while aiming to improve the reliability, a reliability management method with regard to the design, manufacturing and maintenance of wind turbines was proposed.

Contents

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1. Introduction

Renewable energies represent a cornerstone that steers our energy system in the direction of sustainability and supply security [1,2]. Wind is one of the world's fastest-growing renewable energy sources. The rapid growth in wind power is a result of improvements accomplished in technology [3]. The worldwide demand for renewable energy is increasing rapidly because of climate problems and limited oil resources. Electricity generated from wind power currently represents only 3.86% of global electricity production with 318.1 GW of wind power operating in 103 countries [4]. The world's wind energy capacity has been increasing year after year and is expected to continue increasing [5].

As a renewable and clean source of energy, wind energy has been developing rapidly in China in recent years and has become China's third energy source, following thermal power and hydropower [6]. In the last several decades, the total installed capacity of wind energy in China is approximately 91 GW, and even though the new installed wind turbine capacity in 2012 was 26.5% less than in 2011, it still exceeds 13 GW. From 2013, the market environment for wind energy began to recover, and the expected new installed capacity will be 15–18 GW in 2014. At the same time, China's wind power industry has entered into a transformation period by focusing on quality instead of quantity [7–9].

However, more problems arose with the growth in capacity. In 2010, there were 80 off-grid accidents with wind turbines in China, and in 14 of them, the lost power exceeded 100–500 MWh. In 2011, the number of off-grid accidents reached 193 in the first eight months, and the number of accidents with a 100–500 MWh power loss were 54 [10]. Meanwhile, other wind turbine failures, e.g., nacelle fire and tower collapse, also occurred at the wind farms of the Liaoning, Inner Mongolia, Gansu and Jilin Provinces (Figs. 1 and 2). Although most of the failures were attributed to the chaos of wind farm construction, the violation of wind energy grid-connected standards and the examination lag has led to a greater focus on wind turbine quality.

Due to the emerging energy crisis and growing environmental pollution in China, strengthening the exploitation and utilisation of renewable energy sources, which has caused increasing concerns from the government and social sectors, becomes an important energy development strategy. The new installed wind turbine capacity doubled each year from 2005 to 2010, and in 2010, the new installed capacity was over 18,000 MW and the total installed capacity reached 44,733 MW in China, both of which ranked as first in the world (Fig. 3) [11]. Nevertheless, hidden problems emerged during the rapid expansion. From January 2009 to December 2012, China had 37 wind power catastrophic failures in which 34 were turbine failures and 3 were component failures, and 34 wind turbines collapsed or burnt down (Figs. 1 and 2) [12]. Quality issues are becoming the priority of wind turbine manufacturers [7,13]. Although the new installed capacity for China in 2012 declined dramatically, and it was difficult to revive the wind power industry in 2013 (the new installed capacity in China was 16,089 MW in 2013 [14]), wind power has strong potential as the primary focus of China's renewable energy policies.

2. Current status of wind turbines in China

2.1. Main configurations of wind turbines in China

The first wind turbine developed in China dates back to the 1970s, which joined the power grid in the Sijiao Island, Zhejiang Province. After the 18-kW wind turbine, 200 kW, 250 kW, 600 kW, and 750 kW fixed pitch wind turbines were developed, and the MW level wind turbine was developed in 2003. Currently, the majority of wind turbines in China are 1.5 to 3 MW. In 2013, the 6-MW offshore wind turbine succeeded in power integration, and the 12-MW turbine is under study [15].

Fixed pitch wind turbines are no longer in production due to the evolution of wind power technologies. There are mainly three configurations of pitch controlled wind turbines in the Chinese market.

2.1.1. Doubly Fed Induction Generator (DFIG) with gearbox

This type of wind turbine incorporates the blades, multi-stage gearbox, DFIG, frequency converter and control unit (Fig. 4). The blades drive the gearbox, and in turn, spin the generator to output electricity. The stator of the DFIG is connected directly to the grid, while the rotor circuit is attached to a bi-directional AC–AC, AC–DC–

Fig. 1. 1.5 MW wind turbine nacelle fire in Xilingol wind farm in Inner Mongolia.

Fig. 2. Collapsed wind turbine tower in North Bridge wind farm in Guazhou, Gansu.

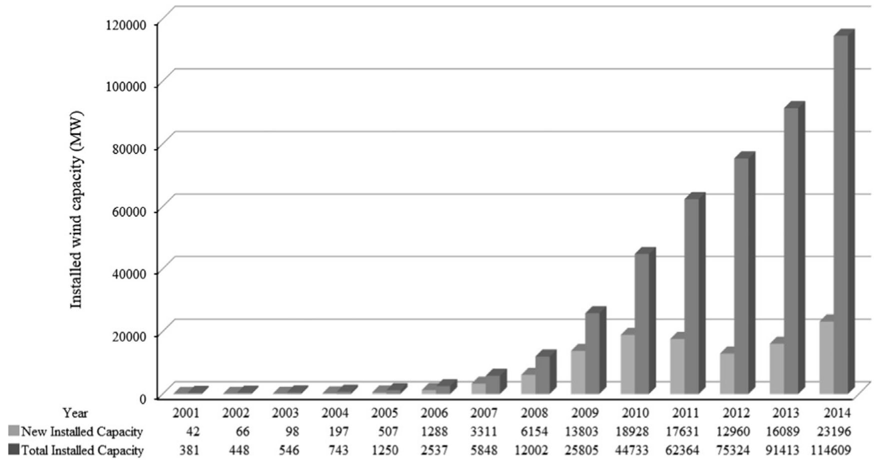

Fig. 3. New and total installed wind power capacity in China from 2001 to 2014.

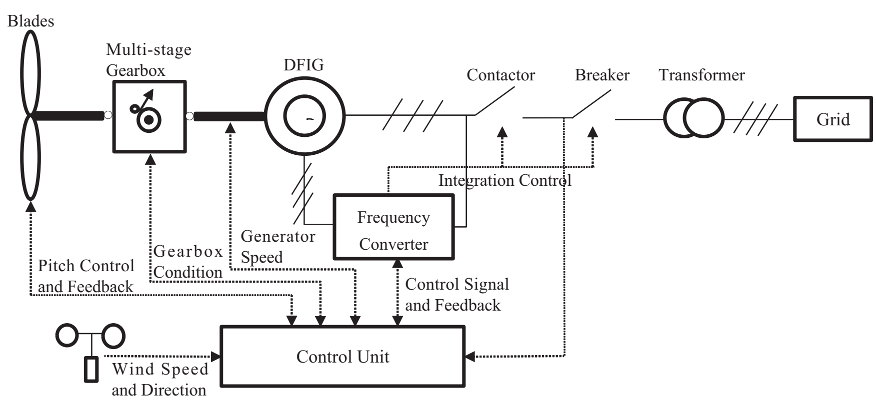

Fig. 4. Structure frame of DFIG with gearbox wind turbine.

AC or matrix frequency converter, which regulates the frequency, phase, amplitude and phase sequence of the rotor circuit [16].

2.1.2. Direct drive Permanent Magnet Synchronous Generator (PMSG)

The direct drive PMSG wind turbine mainly consists of the blades, direct drive PMSG, power converter and control unit. This type of wind turbine is characterized by a gearless drivetrain, which indicates that the blades drive the generator directly (Fig. 5). The pole number is approximately 100, and a full-scale power converter is employed to control the speed of the PMSG [17].

2.1.3. PMSG with single/double stage gearbox

In type (a), the multi-stage gearbox yields a high failure rate, while in type (b), the generator is expensive, bulky and heavy because of the large number of poles. This type is a synthesis of type (a) and type (b). The so-called “Multibrid” is comprised of the blades, gearbox, generator, power converter and control unit in which the gearbox is single/double stage and the generator is a low-speed PMSG with fewer poles than the direct drive PMSG (Fig. 6) [18].

Type (a) is the most common wind turbine in China, commanding over 70% of the wind turbine market. Type (b) is mainly manufactured by the Goldwind and Xiangtan Electric Manufacturing Group (XEMC) and shares 20% of the Chinese market. The first multibrid wind turbine was developed and the power was incorporated by the Hafei Industry in May, 2009. At present, the Goldwind 3-MW wind turbine and the China Creative Wind Energy 3.6-MW wind turbine are both type (c). Additionally, Dongfang Electric Corporation is also devoted to the multibrid technology. The top nine manufacturers of the total installed wind capacity in China and their major turbine models are listed in Table 1 [19].

2.2. Wind turbine reliability in China

Wind turbines in China are designed based on the Wind Turbine Specifications released by the China Classification Society in 2008 [20], which stipulates that the lifecycle of a wind turbine should be over 20 years and the annual availability should be 97%. According to the 2010–2012 Quality Report of the China Wind Turbine Facilities by the Chinese Wind Energy Association (CWEA), the average annual availability from 2010 to 2012 is 0.9599, 0.9664, and 0.9766, respectively [12]. Although the availability of wind turbines made in China is increasing each year, it is still lower than the number of turbines made by foreign manufacturers [21].

Generally, a bathtub curve was used to describe the wind turbine failure process, comprising three periods as shown in Fig. 7. The three periods include a starting period with running-in failures, a period with constant failure intensity and an increasing failure intensity period at the end [22,23]. Many newly developed wind turbines were installed in China in recent years, and the design period for most of them was short, especially in 2008 and 2009 during which wind energy developed rapidly in China [24]. Consequently, some of the installed wind turbines in China are often in the period of early failures and have a high failure rate.

The lost energy of a certain wind farm due to wind turbine failures is shown in Fig. 8. The wind farm was set up in 2004 in Inner Mongolia [25]. We can see from the figure that the lost

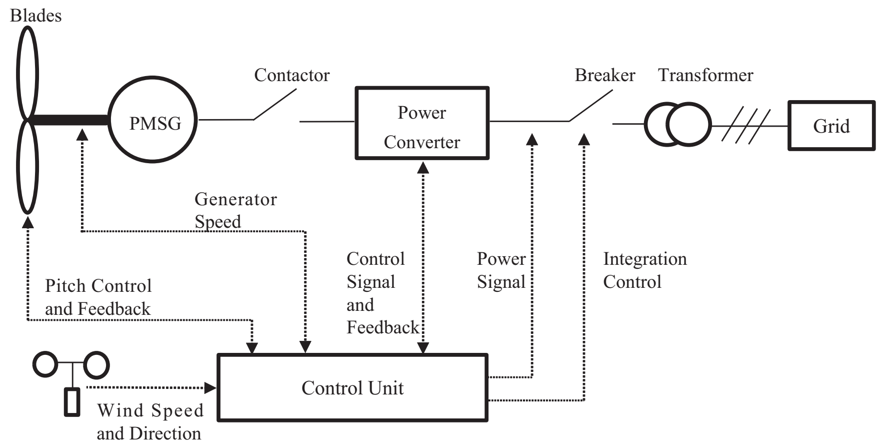

Fig. 5. Structure frame of direct drive PMSG wind turbine.

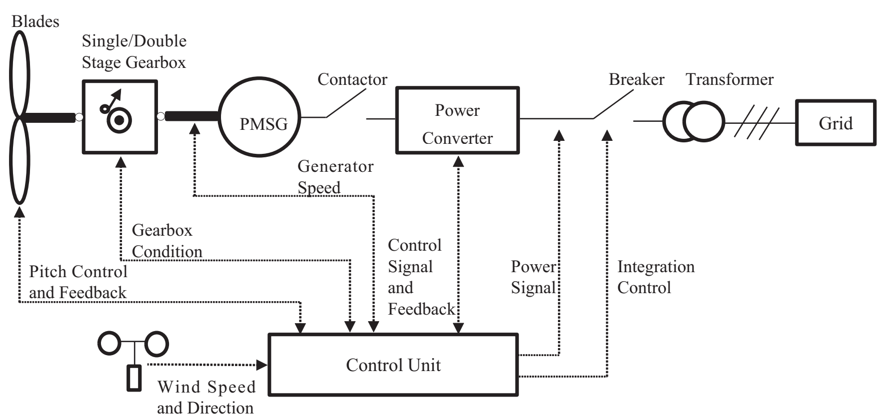

Fig. 6. Structure frame of multibrid wind turbine.

energy in the first three years is more than that in the last two years due to the high failure rate in the early period.

The annual availabilities of the three above mentioned wind turbine types are compared in Fig. 8. Since the early stage of R&D, the availability of the multibrid wind turbine type was the lowest in 2011. However, in 2012, it was the highest, fully embodying the advantage over the other two types.

3. Common failures of wind turbines in China

According to the investigation on the 47 Chinese wind turbine manufacturers, component suppliers and developers (their wind farm number was 111 in 2010, 560 in 2011 and 640 in 2012) conducted by CWEA, most wind turbine failures are due to the following component failures: frequency converters, generators, gearboxes, pitch systems, yaw systems, blades and braking systems, as shown in Fig. 9.

3.1. Frequency converter failures

The frequency converter is an important component in wind turbines. The stators of the generator in the semi-direct and direct drive wind turbines are connected to the grid via full-scale AC–DC–AC frequency converters [26,27], while the stators of the DFIG wind turbines are via partial-scale AC–DC–AC frequency converters [28]. Frequency converters yield the highest failure rate among all of the components (Fig. 10). Once the frequency converter fails, the power supply quality will decrease, and even the entire generation system and the power grid will be in danger if this failure is not handled in time. The 1.5-MW wind turbine nacelle fire in February 2012 in Inner Mongolia was caused by a frequency converter failure.

The frequency converter contains various and numerous electronic components; thus, the failures are diverse and are mostly short or open circuits of resistors, capacitors and power switches. The insulated gate bipolar transistors (IGBTs) are popular power switches in wind turbine frequency converters. If the voltage is too high and the working power surpasses the maximum dissipation power at the operational temperature, the power switches would breakdown or burn out due to the high temperature. In addition, the frequency converters would fail if the grid fails and the DC and power side voltage is high, or the generator load changes suddenly and an impulse current is introduced, or the insulation aging of cables causes an interturn or interphase short circuit [29–31].

The heat dissipation of the frequency converter includes air cooling and water cooling. If the cooling system is damaged or is not functioning well, the temperature of the frequency converter cabinet will be too high and the reliability of the delicate power electronic components will decrease [32]. Moreover, the frequency converter will fail under a low temperature environment. The average temperature in Inner Mongolia, Xinjiang and other northern parts of China is approximately −20 °C and even −30 °C in winter; thus, the failure rate is high in winter [33].

Table 1
Top 9 manufacturers of total installed wind capacity in China with major turbine models.

Manufacturer	Model	Power (kW)	Type
Goldwind	GW66;GW70;GW77	1500	b
	GW82;GW87;GW93	1500	b
	GW90;GW100;	2500	b
	GW103;GW106	2500	b
	GW109	2500	b
	GW3.0 MW	3000	c
Sinovel	SL1500/xx	1500	a
	SL3000/xxx	3000	a
	SL5000/xxx	5000	a
	SL6000/xxx	6000	a
Dongfang	FD70D;FD82B;	1500	a
	FD89B;FD93H	1500	a
	FD87A;FD93B;FD108C	2000	a
	FD108B	2500	a
	FD119A	3000	a
	FD127;FD140	5500	a
Guodian U.P.	UPxx/1500	1500	a
	UP2000-xxx	2000	a
	UP100;UP108;UP120	3000	a
	UP6000-136	6000	a
Mingyang	MY1.5	1500	a
	MY2.0	2000	a
	MY3.0	3000	c
XEMC	XExx-2000	2000	b
	XExxx-2500	2500	b
	XExxx-3000	3000	b
	XExxx-5000	5000	b
Shanghai Electric	W1250-xx-xx	1250	a
	W2000-xxx-xx	2000	a
	W3600-xxx-xx	3672	a
CCWE	CCWE1500/70	1500	a
	CCWE1500/77	1500	b
	CCWE2000/103	2000	b
	CCWE3000/103.D	3000	b
	CCWE3000/103.DF	3000	a
	CCWE3600/115.HD	3600	c
Windey	WDxx-1500	1500	a
	WDxxx-2000	2000	a
	WDxxx-2500	2500	a
	WDxxx-5000	5000	a

3.2. Generator failures

Generator failures are also common in wind turbines and mainly include mechanical failures, electrical failures and cooling system failures. The mechanical failures are mostly rotor failures and bearing failures. Rotor failure includes the unbalanced rotor, rotor crack and loosening socket, while the bearing failure includes fatigue failure and the instability of the oil film. Mechanical failures are caused by mechanical components such as bearings, shafts and couplings, and electrical failures are divided into stator winding failures and rotor winding failures. The failures of generators were mainly caused by short circuits that result in tri-phase asymmetry. Many factors are responsible for the occurrence of short circuits, e.g., the insulation damage of the conductive part in electrical devices, operating the disconnector switches with load, power on prior to the demolition of the old cables after inspection, and natural phenomena such as wind, rain and snow. Cooling system failures are caused by the long-time high temperature of the oil that results in damage to the generators, and the main reasons for these failures are jams in the oil circulating systems, oil leaks, defective pipelines and oil deterioration [34–37].

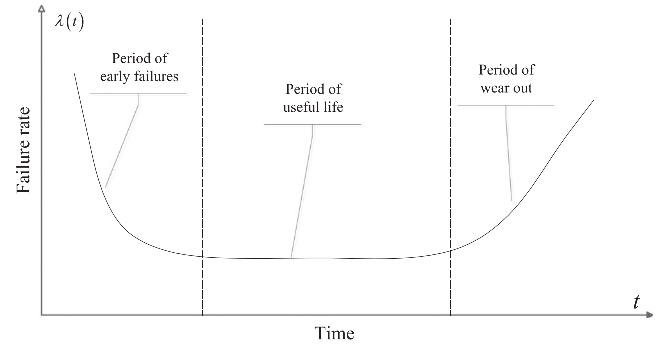

Fig. 7. Wind turbine failure rate vs. wind turbine life.

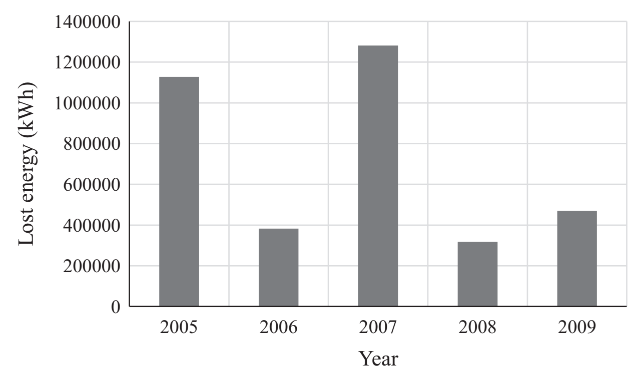

Fig. 8. Lost energy of a certain wind farm from 2005 to 2009.

3.3. Gearbox failures

Gearbox failures exist mainly in DFIG wind turbines that use high-speed ratio gearboxes [38]. Primarily, there are three types of failures as follows [39–41].

a) Teeth surface pitting. It is the main failure mode of gearboxes. Under the comprehensive function of the lubricant, by varying contact stress and friction, the gears craze under the teeth surface and gradually evolve into pits on the teeth surface. Aggravation of the pitting will bring forth strong vibration and noise and finally lead to malfunctions in the wind turbines.
b) Teeth bonding. For large wind turbines, teeth flanks are subjected to large stress and high sliding speed, which results in transient high temperatures under bad lubricant conditions; thus, teeth bonding is formed. It will generate scratches on the teeth flanks and even avulse them in worse cases.
c) Gear fracture. There are two types: fatigue fracture and overload fracture. Due to the instability of the wind speed, the gears are frequently subjected to impulsive load, leading to the impulsive bending stress on the dedendal. The fatigue crazes are thus generated and extended, eventually causing the fracture of the gears. The overload fracture, as the name implies, occurs when excessive load is exerted on the gears.
d) Static indentation. This refers to the strip mark on the tooth surface, even with some pitting around the mark. The main cause for static indentation is the lengthy gear mesh during downtime when some components malfunction and should be replaced.

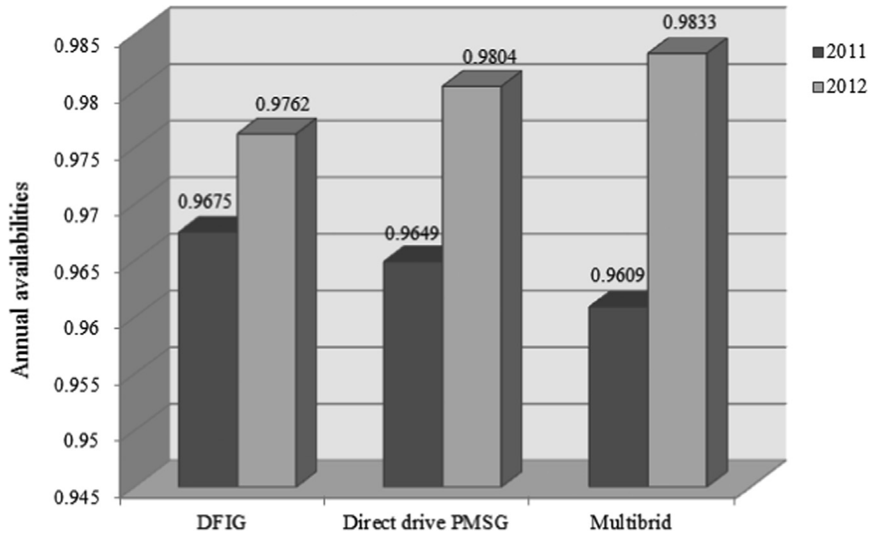

Fig. 9. Annual availabilities of the three wind turbine types in China.

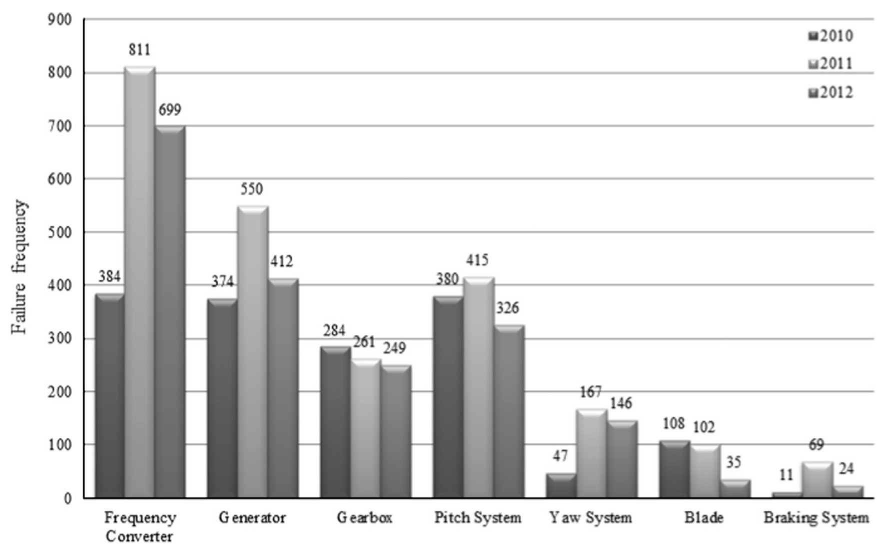

Fig. 10. Component failure frequency distribution for Chinese wind turbines from 2010 to 2012.

e) Bearing damage. This mainly occurs on the bearing balls and the bearing raceways and includes severe wear, static indentation and ball corrosion. It is caused by insufficient lubrication or overload. In addition, different types of lubricant will react chemically and lead to corrosion due to the bad inter-solubility [42].

3.4. Pitch system failures

Two types of pitch systems can be used in wind turbines: electric motor drive and hydraulic drive. Nearly all of the pitch systems in Chinese wind turbines adopt the former because of the hydraulic pitch system's oil leakage and maintenance.

The electric motor pitch system failures mainly include control system failures, mechanical system failures and battery system failures. The control system failures consist of pitch angle faults, overheated motors, and communication malfunctions. The electric motor is the key component of the pitch system. A cooling fan and revolution speed transducer are located at the rear end of the motor, and the brake is in the interior of the motor. The main failures of the motor are short circuits of the winding, brake damage, jams in the bearing and cooling fan errors, as well and overheating or overburning due to oil leakage in the gearbox [43]. The communication malfunction is the main cause for wind turbine runaways [44]. For the wind turbines with gear transmission, the oil in the gearbox will leak to the slip ring and form an insulating oil film between the slip ring and the signal pin, which causes pitch signal intermittence. As for the mechanical system failures, the pitch gearbox failures often result in the overcurrent and temperature rise of the driving motor. The insufficiency of the lubricant would cause damage to the pitch bearings, pitch gears and pitch encoders [45,46]. The battery system failures often manifest when charger faults and charging are not available. If the battery cannot provide sufficient electric power for the pitch motor to feather the blade, the turbine will run away [47].

3.5. Yaw system failures

There are three types of yaw system failures: mechanical failures, hydraulic failures and electrical failures. The mechanical parts are the yaw drive mechanism and the yaw brake mechanism. The most common yaw drive failures are tooth face abrasions, which are caused by particle permeation or a lack of grease [48]. Other yaw drive failures include gearbox failures and yaw bearing failures [49]. The yaw brake failures are mainly brake actuator failures, including braking pad wear, braking pad contamination and braking disc wear [50]. The hydraulic failures consist of hydraulic oil leakage and unstable braking forces caused by hydraulic component failures, while the electrical failures include drive motor failures, yaw counter failures, angle transducer failures and cable abrasions [51,52].

3.6. Blade failures

The blade failures are composed of blade fractures and blade surface cracks. Due to the lack of blade failure test methods, blade surface cracks often evolve into fractures before being discovered. According to the 2010–2012 wind turbine statistics, the most common blade failures in China were blade fractures, which were mainly attributed to manufacturing errors, deformation caused by long-time operation, and blade vibrations. Moreover, lightning strikes can lead to blade explosion and cause shock damage to the blade structure. If the damage occurred at the blade tips, the blade can be repaired; however, in a few cases, the blade should be replaced. In addition, the increase in blade surface roughness caused by dust stratification, icing, insect bodies and chipped paint lowered the energy capturing efficiency, even though no immediate damage occurred on the blades [53].

The transportation and installation will also lead to blade damage. During transportation to the wind farm, blade tips will be scraped by trees and branches sometimes, which will be a hidden trouble in the future. If the centre point of the blade is not with the girder angle during the installation process, there will be angle restoration and friction restoration and it will damage the front edge of the blade [54].

3.7. Braking system failures

The wear of the braking discs is the most common failure in braking systems. Moreover, malfunctioning hydraulic components or the leakage in hydraulic systems will result in irregular braking force or even no braking force. When the coupling between the electric motor and the hydraulic pump break down, the pump will be in the overload status. In addition, air mixing in the hydraulic system will result in the slow actuation of the brake caliper, and long braking time and insufficient braking torque will come up when the braking disc and braking pad are contaminated by the oil or the spring in the actuator is damaged. The misoperation of the braking systems will emerge when the sensors (pressure sensors, oil temperature sensors, rotational speed sensors, etc.) malfunction [55,56]. As a maintenance routine, the braking disc should be magnetic particle inspected to check if there are any cracks inside the disc.

3.8. Sub-synchronous resonance in wind turbines

Sub-synchronous resonance (SSR) is related to a resonance situation that led to the energy exchange between the generator and the transmission line, which may lead to serious damage in generator units. There are several methods for analysing the SSR including frequency scanning [57,58], eigenvalue analysis [59,60], and electromagnetic transient analysis [61], which are the most used methods. One of the most common methods used to reduce the SSR is installing auxiliary devices in the power system, such as the NGH-damping scheme [62], blocking filter [63] and flexible AC transmission system (FACTS) device [64].

4. Fault analysis of wind turbines in China

As an integration of mechanical, electrical and control systems, wind turbines have numerous components and various types of failures as follows.

4.1. Lack of core technologies, inferior quality due to price competition

By far, wind turbine manufacturing technologies in China are obtained through licensed production, co-production and joint venture production with foreign corporations. The core technologies and independent innovation capability is the key to most wind turbines. Imported drawings are expensive and are also sold to other organisations, which wastes a considerable amount of money and leads to homogeneous competition among local corporations. In 2010, there were more than 70 wind turbine manufacturers and 300 component suppliers in China. Price competition reduces concerns regarding quality and reliability and even gives rise to cut-corner issues [65].

4.2. Design standards and wind farm climates

The design standards of China's wind turbines are the Wind Turbine Specifications released by the China Classification Society in 2008 and are based on IEC61400-1(2005) and the Guideline for the Certification of Wind Turbines by Germanischer Lloyd. The IEC standard is aimed at the European climate, while in China, the altitude, extreme temperature, humidity and other environmental factors are very different from Europe's parameters. For example, the wind regime in China is gusty, and the gust intensity may exceed the IEC standard. The average turbulence intensity is approximately 58 to 156% higher in China, and every year, a typhoon strikes China's southern coastal cities. As for the temperature, China has one of the lowest among the same latitude countries in winter. Take January for example. Northeast China's temperature is 15–20° lower than the average temperature in the latitude, and the southern coastal regions are 5° lower. However, in summer, China is among the highest temperature countries in the same latitude. In July, northeast China's temperature is 4° higher, and south China is 1.5–2° higher [66].

In 2011, the National Energy Administration of China published two industrial standards, which are “Wind turbine generator system technical specification of electric pitch system” [67] and “Technical specification for main control system of doubly fed wind turbine generator system” [68], respectively. The two technical specifications were developed based on local wind energy features and the current status of the wind power industry in China and will guarantee positive development in the industry. Furthermore, there will be another 38 industrial standards published in 2015 and 2016 from which we can see the amount of attention that the National Energy Administration has given to the standards and how important the design standards are to the wind power industry.

4.3. Quality certification

At present, wind turbine certification in China is not mandatory but voluntary; thus, some wind turbines are used without a quality test. Moreover, a few certifications for wind turbines are not “true” certifications. Some wind turbines simply do the validity verification without modelling the test and assessment on IEC required materials. Other wind turbines acquire quality certifications; however, the manufacturers or the wind farm operators alter the models or suppliers of some components based on their own demands [69], which may also lead to wind turbine failures.

4.4. *Exterior factors such as wind farm construction, power grids and maintenance*

Except for the wind turbine itself, the exterior factors also play an important role in wind turbine quality. In the early stage, wind farm construction did not attract considerable attention from the wind farm operators, especially because the wind speed measurement is not accurate and intact. In recent years, this situation has been improved; however, the wind speed data are analysed and processed through foreign software, which is not designed and optimised for the Chinese geographical environment and wind resources. As for the power grid, northeast, northwest and north China have abundant wind resources and weak power grids. A large-scale grid connection will provide a powerful impact on the grid. Meanwhile, the grid has a higher standard for the wind turbine technologies, such as low voltage ride through (LVRT) [70]. The demand for wind farm maintenance is growing with the installed wind turbine capacity, especially when the wind turbines are beyond their warranty and the manufacturers do not offer operating maintenance. There are few technicians and canonical management in wind farm operations, and the wind turbine models are varied, leading to the catastrophic failure of wind turbines.

5. Management method to improve reliability

In addition to the technologies, the management method is also crucial to wind turbine reliability. Reliability management should be conducted throughout the design, manufacturing and maintenance stages.

5.1. *Reliability management in design stage*

First, present the wind turbine design goal based on the demands and wind farm climate. Second, perform the reliability design using the failure mode and effects analysis (FMEA) and fault tree analysis (FTA) on the basis of component reliability data. Finally, gather the design, manufacturing, transport and maintenance engineers to perform a systematic and thorough evaluation to detect defects at the early stage and minimise loss.

5.2. *Reliability management in the manufacturing stage*

Design lays the foundation of reliability, while manufacturing realizes the reliability. Reliability management in the manufacturing stage, including technique reliability management, operation staff management, instrument reliability management and product quality inspection management, ensures the satisfaction of the designed technical requirements. Product quality inspection management requires a performance test by both the manufacturer and professional institutions. On September 6, 2013, the national centre for wind power technology and testing was founded in Beijing. The affiliated Zhangbei test site has 30 stationary test machines and 21 sets of field test equipment, including grid disturbance simulation devices and voltage drop generators. Eleven branch centres were set up in the provinces with more than 1000 MW installed capacity, which provide excellent facilities for wind turbine inspections and tests.

5.3. *Reliability management in maintenance stage*

Reliability management in the maintenance stage refers to the formulation of maintenance methods, the guarantee of spare maintenance equipment and the collection and analysis of maintenance data. The collection and analysis of maintenance data are crucial to the reliability of design and manufacturing and helps improve the techniques of design and manufacturing to reduce the failure rate. The communication and sharing of the maintenance data analysis among wind turbine manufacturers, component suppliers and wind farm operators contribute to the improvement of wind turbine reliability. Therefore, it will be a significant act to establish the wind turbine maintenance information network.

6. Conclusions

1) On the basis of an analysis of the current status of wind power development in China, this paper indicates that the installed wind turbine capacity grows rapidly; however, most wind turbines are in the period of early failures and have a high failure rate.
2) The failure types and failure sources of frequency converters, generators, gearboxes, pitch systems, yaw systems, blades, braking systems and sub-synchronous resonance (SSR) are analysed. Although there are many failure types and various causes, we can deduce four primary reasons for these failures: lack of core technologies, inferior quality due to price competition; design standards and wind farms climate differences; and no mandatory quality certification and exterior factors such as wind farm construction, power grids and maintenance. The National Energy Administration of China is giving more attention to developing industrial standards based on local wind energy features and regulating the wind power industry.
3) In addition to the technologies, the management method is also important for wind turbine reliability. The reliability management methods in the design, manufacturing and maintenance stages are proposed to improve the reliability of wind turbines.

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