Wind Energy Power Prospective

Carlos Quiterio Gómez Muñoz and Fausto Pedro García Márquez

Abstract Wind energy and its perspective is introduced and described in this chapter. Wind farms, in contrast to conventional power plants, are exposed to the inclement and variability of weather. As a result of these variations, wind turbines are subjected to high mechanical loads, which require a high level of maintenance to provide a cost-effective power output and care the life cycle of the equipment. The demand for wind energy continues to rise at an exponential rate, due to the reduction in operating and maintenance costs and increasing reliability of wind turbines. Wind turbines make use of condition monitoring systems that allow information to be gathered regarding the condition of the main components, and determine anomalous operating situations. The power generation plants have incorporated a basic online monitoring control system. This system generally includes sensors for monitoring key machine parameters, such as temperature, speed, fluid levels, unbalance in the rotor, etc.

1 Introduction

The renewable energy industry is in a constant improvement in order to cover current demand. Wind farms, in contrast to conventional power plants, are exposed to the inclement and variability of weather. As a result of these variations, wind turbines are subjected to high mechanical loads, which require a high degree of maintenance in order to provide a cost-effective power output and maximise the lifetime of the equipment [1–3]. The demand for wind energy continues to grow at an exponential rate, due to the reduction in operating and maintenance costs and increasing reliability of wind turbines [4, 5].

Wind turbines make use of certain monitoring systems that allow evaluation of the status of critical components, as well as to determine anomalous operating

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situations. Power generation plants have incorporated a basic online monitoring control system. This system generally includes sensors for monitoring key machine parameters, such as temperature, speed, fluid levels, unbalance in the rotor, etc. [6].

Condition Based Maintenance (CBM) is an advanced maintenance strategy based on ascertaining the machine status using monitoring data. It is based on obtaining condition monitoring measurements from key wind turbine components [7–11]. The main objective of CBM is to optimise maintenance activities and reduce costs [12, 13].

The challenge for the future is to get a cheap source of energy, non-polluting, renewable and accessible to all countries in the world, allowing to reduce dependence on fuels to households, industries and transportation. Current data on wind power places it as the main renewable energy source globally. Its importance in the energy market is essential and all indicators show that this trend will continue in the near future.

This industry requires therefore of significant improvements in reliability, lifetime or availability that it is done by an efficient maintenance based on condition monitoring systems. Modern wind turbines need also an autonomous condition monitoring system because of the associated repair costs, especially for offshore plants, where any repair actions can extend several weeks due to the difficult working conditions [14].

2 Wind Turbines

Wind energy is gradually becoming more competitive in comparison with other energy sources [15]. Significant improvements in reliability, lifetime and availability can be expected from efficient maintenance and repair strategies on the basis of condition monitoring systems (CMS) [16]. The new wind turbines require of CMS in order to reduce the maintenance and operations costs, especially in offshore machines, where any corrective/preventive maintenance task can require several weeks before it can take place due to the deployment difficulties arising from weather and sea conditions as well as availability of appropriate vessels [17].

The evolution of wind energy over the past 15 years suggest that its importance will continue to grow in the future and will remain in a relevant position within renewable energy in the global energy scene [18].

Figure 1 shows the annual installed wind power capacity in the world from 1997 to 2014.

Wind Turbines (WT) are typically subject to high and varying loads, as well as extreme weather conditions. Consequently, the operational unavailability of Wind turbines reaches 3% of the lifetime of a Wind turbine. The operation and maintenance costs can account for 10–20% of the total Levelised Cost of Electricity (LCOE) and can reach 35% towards the end of the wind turbine lifetime.

A high degree of maintenance is necessary to provide safe, cost-effective, and reliable wind power generation [20]. This is even more critical for offshore wind farms (Fig. 2), where turbines cannot be reached during adverse weather conditions.

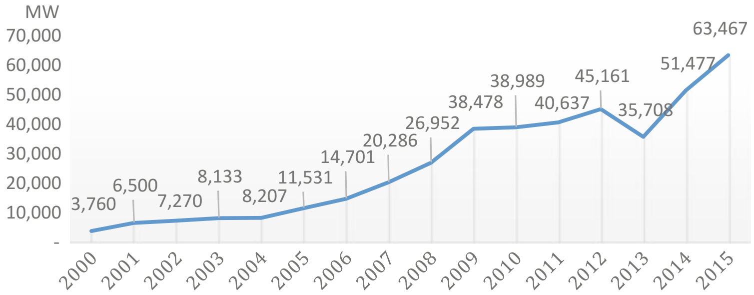

Fig. 1 Annual installed wind power capacity in the world [19]

Fig. 2 Offshore wind turbine in the wadden sea

Condition monitoring (CM) is defined as the process of determining the condition of system using various sensor measurements [9, 10, 22]. The main propose of CM is to identify a significant change in the condition of the system or its subcomponents which is indicative of a developing fault. It is usually considered as part of a predictive maintenance strategy, in which maintenance actions, and therefore preventive maintenance tasks, are scheduled to prevent failure and avoid its consequences [13, 23, 24]. The objective is to extend the life cycle of the system analysed, and to avoid major failures, resulting in considerable cost and associated downtime reduction.

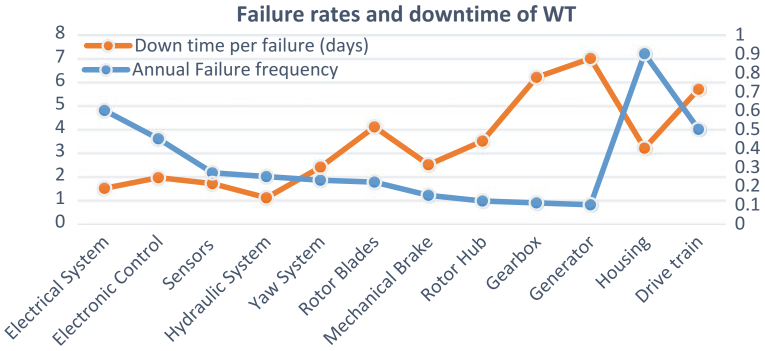

Fig. 3 Failure rates and downtime from two large surveys of European WTs over 13 years

Approximately 75% of the annual downtime in wind turbines is caused by only 15% of the failures [25]. It is more relevant to increase the condition monitoring in those parts that cause downtime bigger, not those having more failure rate [26].

The results published by Haln et al. [27] presents the average failure rate and average downtime per component. Figure 3 shows the three groups that cause the majority of downtime, i.e. the blades, gearbox and drive-train. Condition monitoring efforts should focus on these parts.

In the field of wind turbine, condition-monitoring is used to determine the optimum point between corrective and scheduled maintenance strategies [25, 28–30]. Maintenance approaches in the wind energy industry can be classified into three main groups:

- Corrective maintenance: The reaction is initiated after the failure occurs.
- Preventive maintenance: The operative period of a wind turbine is around 20 years [27, 31] and most of the failures are predictable using time-based strategies.
- Predictive maintenance. This strategy is based on the condition of the wind turbine. By knowing the structural condition of the parts of the machine it is possible to detect defect in an early stage.

There are several non-destructive testing (NDT) methods for structural health monitoring of wind turbine blades, such as acoustic emission [12, 32, 33] or conventional ultrasonic inspection [32, 34–37].

2.1 Wind Turbines' Blade Failures

Some Wind turbine blades are made from composite materials based on glass fibres. Normally a spar made also of composite materials which can also be based on tape wound fibre glass or in larger blades of carbon fibre, supports the outside glass fibre composite skin of the blade and provides structural stiffness. The need to manufacture blades with a complicated geometry due to the aerodynamic efficiency requirements, low weight and satisfactory mechanical properties has led to the use of composite materials by default. One of the important factors is the resistance of such materials to fatigue damage initiation and propagation. Also these materials have low thermal expansion and low thermal conductivity.

A composite material is formed by long and straight fibers impregnated within a polymeric matrix that surrounds, binds and protects fibres. Laminates are made by superimposed layers of fibres in the thickness direction. The material properties depend on orientation, stacking sequence and physical properties of fibres as well as the choice of matrix material. Sandwich structures are composed of two outer skins covering a material that is lightweight called core. The set results in a material of high rigidity and light weight. The core is thick compared to the outer skins and has a much lower density. The core function is to prevent relative movement of the skin. To lower production cost E-glass fibres are most widely used in combination with epoxy resins. Icingblade Failures. Wind farms are located in areas with suitable wind characteristics.

Icingblades has become a problem in regions where climatic conditions can lead to icing almost throughout the entire year. The ice affects the aerodynamic efficiency increasing the surface roughness and reducing power output efficiency of wind turbines. It also causes imbalance of the rotor, leading to higher stresses being applied on both the blades and the drive-train. The wind turbines require to be stopped until de-icing has been completed causing significant production losses and associated costs.

A study conducted during the *IcingBlades* research project [38] revealed that 517 wind turbines, with a total installed power output of 682 MW, failed to produce 18,966 MWh over a 29 month period solely due to ice on the blades in Spain. This energy loss is practically equivalent to the sum of all major incidents: gearbox replacement, generator replacement, etc. [39]. Extrapolating these figures to Spain, with more than 21,000 MW installed, this would be equivalent to a production loss of 550 GWh and, therefore, 45 million € every 29 months. The avoidance of these production losses would be equivalent to the consumption of 200,000 homes and 658,682 tonnes of CO_2.

Onshore wind farms are usually located in elevated areas in order to get the maximum wind velocity [40]. Suchg locations are often exposed to freezing temperatures, presenting multiple problems due to icing of blades and resulting power generation losses and costs [41]. The WECO (Wind Energy in Cold Climate) project analysed the ice effects, energy generation and icing in wind turbines. It is estimated that 20% of the wind farms are installed in areas with high probability of icing [42].

2.1.1 Ice Formation

Parameters such as temperature, wind speed, relative humidity or air density, among others, condition the ice appearance (see Fig. 4). A classification of different types of icing is presented in reference [43], discerning between in-cloud icing and precipitation and hoar frost. In-cloud icing appears when the atmospheric temperature is below 0 °C and the humidity is high. Super-cooled water droplets hit the surface of the structure and freeze at the time of impact. The major problem is the accumulation of different layers of this kind of ice.

Frost is the most common cause of ice appearance in wind turbines. It grows in all parts of the wind turbine but the onset occurs in the leading edge of the blades, owing the incident velocity [44, 45].

2.1.2 Wind Turbine Phases During Ice Accretion

Wind turbines do not operate properly when ice accumulation is considerable. Consequently, the machines need to be stopped. In the first stage, prior toicing, the wind turbine is working in optimal conditions. In a second stage, icing starts but the wind turbine can operate until it reaches the icing limit alarm. In the third stage, the ice accumulation continues and the turbine needs to be stopped to prevent possible damage from occurring [46]. In the last stage, post-icing, the turbine continues to be stopped until the ice is completely removed.

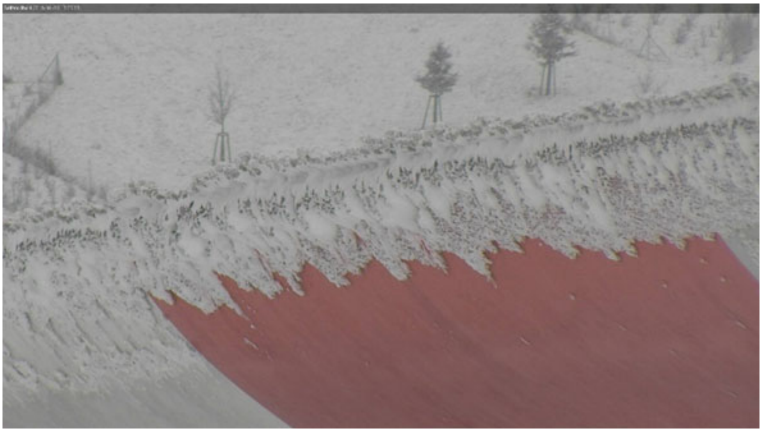

Fig. 4 Ice at rotor blade of a wind turbine

The objective for the ice prevention or removal systems is the reduction of the wind turbine downtime. The mitigated wind turbines are those with a system incorporated in order to deal with ice accretion. During the icing stage, the ice growth is controlled by the system installed in order to avoid the alarm, reducing the necessary downtime to remove the ice from the turbine. When the accumulation is significant, the alarm appears and the wind turbine is stopped until the ice is removed. Downtime is lower than those in the non-mitigated machines. During post-icing the wind turbine can operate [47].

2.1.3 Failures due to Icing and Cold Climate in Wind Turbines

The main problems due to icingblades can be summarised as [48]:

- *Power loss by the reduction of aerodynamic efficiency*. The presence of ice modifies the aerodynamics of the blades by increasing the coefficient of friction and making turbulences, vibrations and noise, as well as a reduction of revolutions.
- *Loads on turbines*. The icing on blades makes loads on the turbine. Icing causes an increase in mass, drag coefficient, imbalance of the rotor and vibrations.
- *Influence in the lifetime of the components*. The fatigue due to loads reduces the life expectancy of the components of the wind turbine, e.g. blades, hub, gearbox, shafts, etc.
- *Increased noise generated by blades*. The drag coefficient of the blades increases due to icingblades.
- *Changes in blade surfaces by ice accretion*. The frozen layer modifies the thickness of the boundary layer, and therefore the air transition characteristics on the blade.
- *Safety hazards*. A problem arises owing to that the ice fragments can break off of the blades and can impact against the ground or other objects.
- *Measurement errors*. During the icing process, the anemometers, temperature sensors and wind vanes are exposed to icing conditions, showing measurement errors higher than 40% [49].

Wind farms located in these areas present problems related to icing such as energy losses, mechanical failures, downtimes, problems to access for human resources, measurement errors or safety hazards among others (see Fig. 5). An analysis carried out by the authors, as part of the research project *IcingBlades* [38], showed that 18,966 MWh were lost over a period of 29 months as a sole consequence of blades icing up in a set of 517 wind turbines with a total installed power of 682 MW. This waste is practically equivalent to all the other major stoppages together (change of multiplier, turbine change, and so on). Extrapolating this to a national (Spanish State) level, with more than 21,000 MW installed, this phenomenon would be equivalent to a loss larger than 550 GWh of power production and, thereby, to about 45 million € over every 29 months. Avoiding these

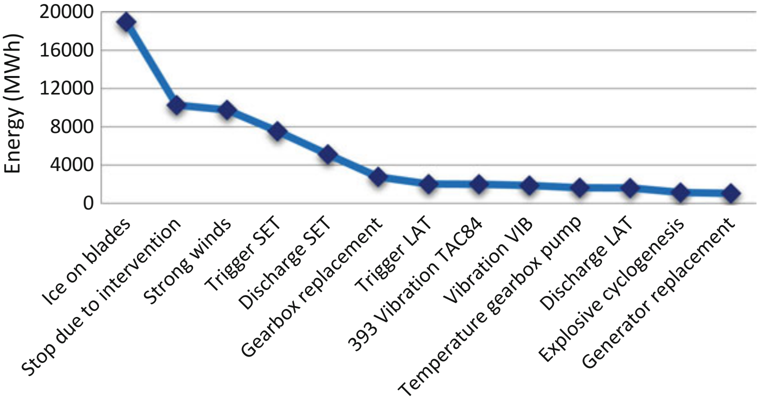

Fig. 5 Power losses due to different alarms in icing blades

production losses would be equivalent to the energy consumption of 200,000 households and savings of 658,682 tons of CO_2. Figure 5 shows the main causes of the production energy losses. Note that ice on blades is the principal one. These energy losses involve an increment of the operation and maintenance (O&M) costs.

2.2 The Soiling and Erosion Failures

Often, the wind farms are in areas difficult to access, making it difficult to evaluate and clean the blades. The accumulation of dirt and mud on wind turbine blades represents a decrease in the performance of power generation. Stall on the blade is occurred due to changes in aerodynamic performance.

Wind turbine soiling is a leading edge surface contamination problem characterized by accumulation of foreign objects on the leading edge [50]. Examples of foreign objects are: insects, mud, dust, salt which collide with the blade when it rotates. The soiling of the blades may be due to factors such as flying insect population, intermittent rain, low humidity and farming activities. The geographical situation and the season also affect the severity of soiling. The accumulation of the foreign objects on the leading edge reduces the blade performance and the energy production, and it increases the noise emitted by the wind turbines (Fig. 6).

Soiling produces disturbances in the air flow, concretely in the layers near the surface, generating a turbulent regime in the air flow and favouring the emergence of the ‘stall’ phenomenon. The kinetic energy is decreased and therefore, the mechanical rotation energy is diminished. Finally, the amount of electricity generated is reduced. Soiling can also reduce the aerodynamic efficiency of the blade which increases noise emissions [51]. In addition, it can be produced false alarms due to the reduction of performance of the wind turbine.

Fig. 6 Soiling of the surface of a WT blade

Other effects of soiling include additional costs associated with the cleaning of the blades. Cleaning WT blades is an expensive operation that requires a special equipment such as cranes, qualified staff, etc. It is necessary also to stop the wind turbine, with the consequent loss of power generation. Some of the efforts to mitigate the soiling problem are shown in references [52–57].

3 Outlook 2050

An important objective of the Wind Energy Roadmap given by the European Commission is: "*improve the reliability of the wind turbine components through the use of new materials, advanced rotor designs, control and monitoring systems*", we propose this PhD research training programme. The key objectives are:

It addresses the needs to design and develop the new technologies essential in overcoming the challenging condition monitoring and control problems currently acting as a barrier to improved wind turbine reliability and reductions in the cost of energy from offshore wind power generation.

Energy security and global warming have led to wind energy becoming one of the fastest growing renewable energy sources (RES) in the world, aforementioned. In the EU, a significant number of offshore wind farms have already been constructed or are being planned; large wind turbines with rotor sizes up to 180 m in diameter (e.g. Vestas 8 MW V-164 with rotor size 164 m) have been or will be manufactured and installed to effectively exploit wind resources in remote offshore areas. Wind energy was a key energy priority of the EU Framework Programme 7, and is one of the main technologies to be further promoted to provide low cost and low carbon electricity in Horizon 2020. The market and technological objectives of the EU wind energy industry are ambitious. In the "Energy Roadmap 2050", the European Commission (EC) expects that by 2050, the share of RES in electricity consumption will reach up to 97% in a high renewables scenario, and the wind power will provide more electricity than any other technologies. In addition, according to "European Wind Initiative: Wind Power Research and Development to 2020", the European wind industry and the EC plan to make onshore wind the most competitive energy source by 2020, with offshore following by 2030, and achieve a 20% share of wind energy in EU total electricity consumption creating 250,000 new skilled jobs by 2020. These give the wind energy industry huge potential for growth both in Europe and globally.

Offshore wind turbines benefit from more favourable wind conditions present in the open sea, as compared to onshore conditions. However, their installation in a remote and harsh marine environment places much greater demand on reliable and sustained operation in order to minimise the need for costly repair and maintenance activities. This poses a major challenge to almost all wind energy related technologies. In order to meet these challenges and satisfy the ambitious demand for wind energy over next two decades, the EC published the Wind Energy Roadmap on 7 October 2009. Following the roadmap, a series of actions were planned to address research, development, and demonstration challenges in the technological areas associated with the widespread implementation of wind energy. A key objective of these actions was to "*improve the reliability of the wind turbine components through the use of new materials, advanced rotor designs, control and monitoring systems*".

4 Conclusions

This chapter book has showed the reasons that justified the development and use of the wind energy in the worldwide from the technical and economic point of view. This industry requires of complex and advanced condition monitoring system in order to increase the reliability, availability, maintainability and safety of the system. It will also reduce the cost and increase the probability.

The main failures are presented, where they are analysed in details for the blades, due mainly by icingblades, and soiling and erosion.

Finally, he main objectives of the wind energy roadmap for 2050 given by the European Commission are analysed and presented.

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