Applications of Metrological Measurement in Wind Power Generation

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Abstract

Development of green energy is the best key for solving environmental problems. The applications of wind force are the most skillful technologies today, which have been as important direction of green energy in highly developed country. Until now the technical development of wind force already achieves the skillful technique of application, and China becomes another leader in this field. Flexibility of modern wind turbine construction becomes more emphasized with the increase in wind turbine size, therefore even bigger vibrational amplitudes. Besides, the supervision blank of the quality of wind power plant by the authority is the reason why manufacture corporation and construction department neglect the quality control. These aspects include: rotor design, improved bearing material and installation, estimation and reduction of frictional effects, improvement in safety and remote monitoring. All of these will require many metrology issues to be addressed.

Keywords: wind power, measurement of wind conditions, mechanical metrology, remote sensing

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1. Introduction

Energy crisis and environmental pollution are the two universal problems which always bother people [1]. Due to double-quick petroleum exhausting in the beginning of last century, the problem of energy crisis today becomes extreme serious.

Wind energy for supply of electricity is a relatively new technology, however, the historical precedents for the wind power can trace back for a long time. With the development of technologies like electronics, computers, control theory, composite materials, and computer-based simulation capability, wind turbines and wind power applications have become so widely deployed over the past twenty years for their autonomously operating and high efficiency characters.

Take Denmark for example. Three-fourths of the country’s wind generation is generated by wind turbines owned and operated by individuals or small cooperatives that generate electricity for their own needs and sell the excess to the local utility. The same to Germany, with the world's third largest industrial economy, now supplies 4% of its electricity from wind turbines. Now after the world, China becomes world's leader in wind power industry in both newly and cumulative installed capacities, installing an impressive 17.6 gigawatts of wind turbines. While on the surface, this relative improvement in grid connectivity appears to be good news for the wind sector, there are a lot of problems in the development of China’s wind power.

2. Wind power accidents and Metrology Supervision

In 2011, China’s electrical generation figures were down 6.9 percent from 2010. The decrease was due to the government bringing in stricter approval procedures for new projects following a series of major faults on its large wind bases [2]. This is not only in China, but also in the global scopes. In UK, the wind energy industry has admitted that 1,500 accidents and other incidents have taken place on wind farms over the past five years [3]. Numbers of recorded accidents reflect this, with an average of 6 accidents per year from 1992-96 inclusive; 22
accidents per year from 1997-2001 inclusive; 70 accidents per year from 2002-06 inclusive, and 133 accidents per year from 2007-2011 inclusive [4]. As more turbines are built, more accidents will occur. Recent years’ accidents of China are presented in Table 1. The data gives the types of accidents which can and do occur, and their consequences. However, before about 2003 only few data on fatal accidents has been found.

Table 1 Chinese main accidents of wind power generation in recent years

<table>
<thead>
<tr>
<th>Type</th>
<th>Date</th>
<th>Place</th>
<th>Details</th>
<th>Figure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal</td>
<td>1992</td>
<td>/</td>
<td>Cleaning blades</td>
<td>/</td>
</tr>
<tr>
<td>Structural failure</td>
<td>2003</td>
<td>Honghai Bay wind works</td>
<td>13 of the 25 units reported to be damaged in the wind power works of Honghai bay following typhoon Dujuan</td>
<td>/</td>
</tr>
<tr>
<td>Structural failure</td>
<td>2006Aug15</td>
<td>Hedingshan wind farm in East China’s Zhejiang Province</td>
<td>Longyuan Electric Power's coastal 15.85 MW wind farm in East China’s Zhejiang Province suffered heavy damage after being swept by Typhoon Saomai and winds of 67 m/s in mid-August. Eight of the 28 turbines installed barely survived.</td>
<td>/</td>
</tr>
<tr>
<td>Structural failure</td>
<td>2006Aug10</td>
<td>Zhejiang Province Cangnan Wind Farm</td>
<td>Super Typhoon destroyed the coastal Cangnan Wind Farm, damaging 20 of its 28 turbines.</td>
<td>Fig.1</td>
</tr>
<tr>
<td>Fatal</td>
<td>2009Jul14</td>
<td>Inner Mongolia’s Xilingol League wind farm Huaneng</td>
<td>Engine room seep oil and result in fire.</td>
<td>Fig.2</td>
</tr>
<tr>
<td>Fatal</td>
<td>2010Jan24</td>
<td>Baolongshan wind turbines</td>
<td>Brake failure, rapid rotation followed by fire and wind tower collapsed</td>
<td>Fig.3</td>
</tr>
<tr>
<td>Material and Installation</td>
<td>2010Jan</td>
<td>Shanxi Province, Zuoyun wind farm</td>
<td>Concussion toughness of flange in low-temperature is failed; Bolt is less of moment; Quality of bolt disqualify; Wind turbines collapsed</td>
<td>Fig.4</td>
</tr>
<tr>
<td>Installation</td>
<td>2010Aug</td>
<td>Gansu Province, Guazhou wind turbines on building</td>
<td>Bolt is less of moment, and wind turbines collapsed</td>
<td>Fig.5</td>
</tr>
<tr>
<td>Environmental</td>
<td>2011Jan6</td>
<td>/</td>
<td>Unregulated Chinese mines repotted as the source for over 95 percent of global shipments of 17 rare earth metals used in wind turbines and other items. The using of rare earth metals caused severe environmental damage.</td>
<td>/</td>
</tr>
<tr>
<td>Environmental</td>
<td>2011Feb24</td>
<td>Jiuquan wind farm</td>
<td>Temperature changes obviously day and night, generating water drops and make the electricity wire short-circuit</td>
<td>/</td>
</tr>
<tr>
<td>Fatal</td>
<td>2011Oct10</td>
<td>Gansu Province Jiuquan wind farm</td>
<td>Suspend of crane ruptured and collapsed, five persons died</td>
<td>/</td>
</tr>
</tbody>
</table>

In the summary of wind turbine accident data [4], until now 107 accidents regarding human injury are documented. 89 accidents involved wind industry or construction/maintenance workers, and a further 18 involved members of the public or workers not directly dependent on the wind industry (e.g. fire fighters, transport workers). Such as in 2011 Oct 10, Gansu Province Jiuquan wind farm, for the quality of suspend of crane, when it suspends the heavy wind power generator, the suspends of crane ruptured and collapsed, five persons died in the fatal accidents.

By far the biggest number of incidents found was due to blade failure. Blade accidents can arise from a number of possible sources, and results in either whole blades or pieces of blade being thrown from the turbine. As turbines become larger, the consequences of such catastrophic failures as throwing a blade raise the stakes for the public at large.

Fire is the second most common accident cause in incidents found. Fire can arise from a number of sources, like the generator rotated too fast and the brake fail to stop it. Other reasons may be oil happen to seep from engine room. The biggest problem with turbine fires is that, because of the turbine height, the fire brigade can do little but watch it burn itself out, and then badly burned wind industry workers or other people.

“Structural failure” is assumed to be major component failure under conditions which components should be designed to withstand. This mainly concerns storm damage to turbines and tower collapse. For the reasons of strong wind, runaway rotor may destroy the whole
generator and operator. However, poor quality control, lack of maintenance and component failure can also be responsible.

The other accidents contain ice throw, transport and installation. Most accidents involve turbine sections falling from transporters or wind power generator from hundreds meters high. If that occurs during high winds, the ice could be blown by the wind some distance from the tower. In addition, it is conceivable that ice could be thrown from a moving wind turbine blade under some circumstances hurt people.

Figure 1. Wind power tower break off

Figure 2. Fire on wind power turbine

Figure 3. Wind power tower buckled and fell to the ground

Figure 4. (a) Ruptured bolts in tubular tower

Figure 4. (b) Cracks between flange and wall of tower

Figure 4. (c) Connection between gear case and principal axis of wheel break off

Figure 5. (a) Wind power on-building collapsed

Figure 5. (b) Wind power generator falls down

3. Mass Metrology in Wind Power Generation

Turbine power scales with kinetic energy density of the air flow over the rotor as the cube of the velocity. It is shown in recent years, with the increase in wind turbine dimensions, the loads that wind turbine has to withstand increase obviously (modern 5 MW wind turbines have tower height over 100 m)[5].

The power output of the turbine can be simulated by

$$ P_{sim}(v, TI) = \int_{v=0}^{v_{0\%}} P_{0\%}(v) f(v) dv, $$

where $P_{0\%}(v)$ is the power given by the 0%-TI power curve for the wind speed $v$ and $f(v)$ is
the wind speed distributions which is assumed to be Gaussian, denoted by \( f(v) = N(v, \sigma^2) \), it only depends on the wind speed average \( v \), and variance \( \sigma^2 \) which is given by \( \sigma^2 = v^2 \times T^2 \).

The turbulence intensity is defined by \( TI = \frac{\sigma}{U} \), where \( \sigma \) is the standard deviation of the wind speed. Moreover, the power that a turbine can extract from a volume of wind is \( P = 0.5 \cdot c_p \cdot A \cdot \rho \cdot U^3 \), \( U \) is the horizontal wind speed, \( A \) is the rotor swept area, \( \rho \) is the air density and \( c_p \) is the power coefficient. Clearly, the power depends on the air density and also the power curve. It result in larger diameter wind-turbines justify larger support structures in order to access higher winds. However, manufacturing of larger structures requires better metrology in terms of supports, rotors, bearings and the alignment of the various items.

As many defects of a turbine can be related to vibrations of the system, the investigation of vibrations caused by rotor imbalances get more and more attention [6].

Higher tip velocities will aggravate blade passing forces, and generate higher turbulent flow forces over the blades, potentially leading to increased noise. The lighter blades will result in higher blade vibration responses to rotational forces off resonance. There are also noise and vibration mitigation strategies which could address these concerns. A simple model based on hemispherical noise propagation over a reflective surface, including air absorption, is given as:

\[
L_p = L_w - 10 \log_{10} (2\pi R^2) - aR
\]

where \( L_p \) is the sound pressure level a distance \( R \) from a noise source radiating at a power level \( L_w \).

Mass imbalances of the blades contribute to forcing both from static imbalance and dynamic imbalance [7]. Static imbalance is a difference between the center of mass and center of rotation of the turbine in the plane of the disk. As the turbine rotates, the center of mass makes a cyclical path, with associated accelerations in the plane of the disk. Dynamic imbalance is associated with a change in the direction of the angular momentum when the turbine rotates. Such a situation arises when the axis of rotation of the turbine is not coincident with a principal axis of the turbine mass distribution. The Ordinary differential equation is like

\[
\mathbf{M} \ddot{\mathbf{u}} + \mathbf{S} = \mathbf{p}
\]

where \( \mathbf{M} \) denotes the mass or inertia matrix, and \( \mathbf{S} \) the stiffness matrix, \( \mathbf{u} \) is the vector of the degrees of freedom of wind tower and \( \mathbf{p} \) is the load vector. \( \mathbf{u}^T = \{v_1, \omega_x, \beta_x, \beta_y, \beta_z, \ldots, v_N, \omega_N, \beta_{xN}, \beta_{yN}, \beta_{zN}\} \) and \( \mathbf{p}^T = \{0, \ldots, 0, F_y, F_z, M_x, M_y, M_z\} \), where \( v_i, \omega_i \) is displacement in \( y \) and \( z \) directions, \( \beta_{xi}, \beta_{yi}, \beta_{zi} \) is cross section rotation, \( F_y \) and \( F_z \) denote forces in \( y \) and \( z \) direction. \( M \) is moment of force or torque. The inhomogeneity of the rotor mass distribution is modeled as point mass \( m \) located in the rotor plane under an angle \( \theta_m \) and a distance \( r \). So \( F_c = \omega^2 mr \) and with \( \omega = 2\pi \Omega \). Then \( (F_c)_z = F_c \cos(\alpha + \phi_m) \) and \( (F_c)_x = F_c \sin(\alpha + \phi + \phi_m) \). For the reason that plane has a distance \( L \) to the tower, and moment is like \( M_z = (F_c)_z \cdot L \) and \( M_x = (F_c)_x \cdot L \).

There are also aerodynamic loads on a wind turbine, the distributed forces and the corresponding lengths are \( F = \int_0^R dF \) and \( l = \frac{\int_0^R x dF}{F} \), more details can be find in [6].

When building up wind turbines beside of gearboxes bearings are vitally for the lifetime of the unit. Very high bending moments, similar to those occurring in actual operation, are applied to these bearings for testing and development [8]. Wind turbines now use some of the largest bearings available. Such bearings are tested on test stands, which require force transducers with a range of 5 Mega Newton, and up to 15 MN in the medium to long term. Traceable calibrations of suitable transfer standards should improve the measurement of force and mass measurement in industrial applications. New types of bearings will require new metrology techniques for measurement of shape to ensure proper alignment and optimization.
4. Conclusion

In recent years, China has identified wind energy as an important alternative power source to rebalance its energy mix. Supportive regulations and policies have been introduced to support this development[9]. But experts point out that the China’s wind farm accident has shown an important warning to us. If we go on ignoring technology standards and lack of coordination between relevant parties, it will become a great problem for new energy power grid connection[10]. Besides, a lack of coordination in review and approval between the regional governments and the national energy administration and state grid was also a leading cause in these accidents.

Many aspects of wind turbines have the potential to be improved including: aerodynamic properties of rotor blades, gearbox longevity, dimensional characterization and force/torque measurement of power transmission components, improved measurement techniques for wind speed. In addition, reliable energy production requires traceable wind speed measurements with low uncertainties. That’s our metrological research institutes should pay more attentions to.

References