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METROLOGY CONSIDERATIONS IN A FAST EMERGING NEW ENERGY SECTOR

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Abstract: The wind energy sector is emerging on the global energy scene as a fast new energy sector. In 2002 the globally installed wind energy capacity passed 32GW, corresponding to 0,4% of worlds electricity supply. The last five years the sector increased in installed capacity by 33% per year. A leading market consulting company forecasts a global installed capacity of 83GW by 2007 and predicts an installed capacity of 176GW in 2012. EWEA/Greenpeace predicts 134GW by 2008 and a penetration of 12% of electricity demand in 2020. In newer times the development of wind energy started in the 70'ies. At the start of an actual market, approval of wind turbines was required on the basis of a public subsidy, and this developed later into requirements of certification. With the technology, measurement procedures were developed to meet the demands. In the 80'ies national and international recommendations were developed. The process of harmonization of procedures started in the late 80'ies, and this lead to the development of international standards within IEC in the 90'ies. Today, the wind energy sector is well established with an international IEC certification standard and attached standards for design and loads, and measurements. Measurement institutes are organized in the MEASNET network and arrange regular conformity testing.

Keywords: standard, measurement, certification

1. INTRODUCTION

When looking at the web site of the World Energy Council [1], the best scenario for development of renewable energy for the energy supplies for the 21st Century do not mention wind energy as a specific significant contributor. Meanwhile, the website indicates a steady decrease in the use of fossil fuels during the century. The web site of IPCC [2], on the other hand, indicates a rather stable temperature over the last 1000 years, but within the last 20 years there is a steep increase of the global temperature of almost 0.5°C. IPCC scenarios predict a temperature increase of 2°C to 5°C over the next century. These mechanisms may be very strong drivers for the wind energy sector for the coming years. The wind energy sector itself has very high expectations to the future. A leading market consulting company, BTM consult, has issued a report, which in figure 1 shows the global development of wind energy until 2002 [3]. The gray area shows global installation of wind energy per year, and the line curve shows accumulated global installed capacity. At the end of 2002 there is a global installed capacity of 32 GW, and over the last five years there has been an exponential growth with a growth rate per year of 33% in average. BTM Consult forecasts a continuation of the exponential growth, see figure 2. The company forecasts a global installed capacity of 83GW in 2007, and they make a less certain prediction of 176GW in 2012. The European Wind Energy Association and Greenpeace are much more optimistic. In their report "Wind Force 12" [4] they predict 134GW by 2008 and a global penetration of wind energy of 12% of the electricity demand in 2020. The background for such optimistic predictions is that the early stages in former predictions have been passed faster than expected.

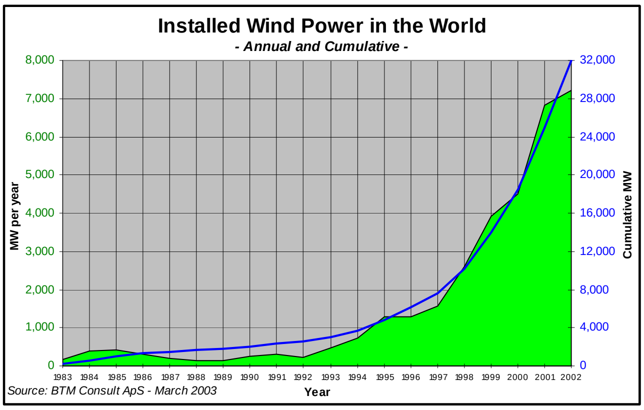

Figure 1 Global installed wind power 1983 to 2002 (BTM Consult)

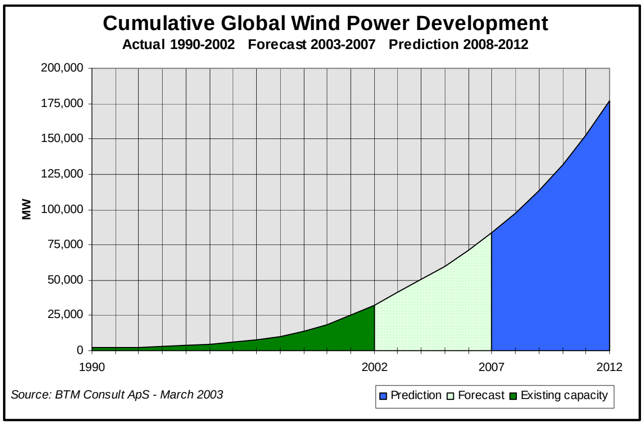

Figure 2 Global installed wind power development, forecasted and predicted until 2012 (BTM Consult)

2. DEVELOPMENT OF THE TECHNOLOGY

The wind energy technology is in a rapid development. Over the last 20 years the average size of the installed wind turbines have doubled almost every 4th year. By the turn of the Millennium the average size was just below 1MW. Today the average size installed is a little over 1MW. Prototypes of 2 to 4,5MW are being tested, and prototypes of 5MW are on the drawing board. The technology at present focuses on offshore installations. Methods of installing wind turbines at water depths of 5 to 15 m are becoming rapidly cheaper. An example is the installation of wind turbines at Nysted off-shore park where the transport and installation vessel in figure 5 could carry four wind turbines at a time in 2003 while it at Horns rev in the Eastern part of Denmark the year before only could carry two wind turbines at a time.

Figure 3 Transport and installation vessel for 160MW offshore wind farm

Offshore wind farms are a rather new technology. In Denmark there are now 6 offshore wind farms with Horns rev of 160MW (2002) and Nysted with another 160MW (2003) as the newest and largest installations. The penetration of wind energy in the Danish electricity system is becoming quite visible. Over the last 7 years the penetration has increased from 4% to about 14%. This would have been 18% for an average wind year. This penetration is quite significant, and it has changed the attitude of the two Danish electricity providers. Today the trend is to consider wind energy as more basic electricity production, and the fossil fuel power plants are used to regulate the electricity production.

3. DEVELOPMENT OF TESTING METHODS

The wind energy sector needs testing procedures to verify performance, loads and safety, and these have been developed since the start of development of wind energy in the 1970'ies, where craftsmen, inventers and even a school in Denmark developed their own concepts. They were technically very different, and for the coming years there was a strong competition to find the most technical and economic sound concepts. For this purpose testing of the designs was essential. At Risø the wind energy activities started in 1979 with the establishment of a test station for small wind turbines on the area of Risø itself, figure 4.

Figure 4 Establishment of test station for small wind turbines at Risø in 1979

The wind turbines that were erected at the test site for small wind turbines came from manufacturers, and two of them were developed from a design competition. There was another national program for big turbines where mostly the utilities were involved. Part of this program was the refurbishment of the old so-called Gedser wind turbine in figure 5. The electricity company SEAS operated this wind turbine successfully for 10 years from 1956. Risø was involved in testing this wind turbine from 1979. The concepts of this wind turbine showed up to be technically very sound. Many of the design principles of this wind turbine were used in the wind turbines that were developed in the 80'ies and 90'ies.

Figure 5 The 200kW Gedser wind turbine, operated successfully from 1956 by the utility SEAS for 10 years

The most important characteristic of a wind turbine is its ability to produce electricity. The economy of a wind energy project depends on the power performance of the wind turbines. In order to measure the power performance one has to measure the available wind resource and the power output of the wind turbine. A mast must be erected with a wind speed sensor to measure the free wind speed. The mast may not be too close to the wind turbine since it will be influenced by the wind speed reduction in front of the rotor. The mast may not be too far away from the wind turbine either since the correlation of wind speed and power is reduced. The power regulation would either be made by feathering of the blades or by provoking stall on the blades. The power regulation at high wind speed was very important. If the power was not effectively controlled, the rotor, gearbox and generator were overloaded. The power performance measurement procedures had to require measurements at these higher wind speeds where power regulation is revealed. The requirements of 3 measurement points per bin up to 20m/s or the cut-out wind speed are shown in figure 6. This is an example from a revised IEA recommendation from 1990 [5].

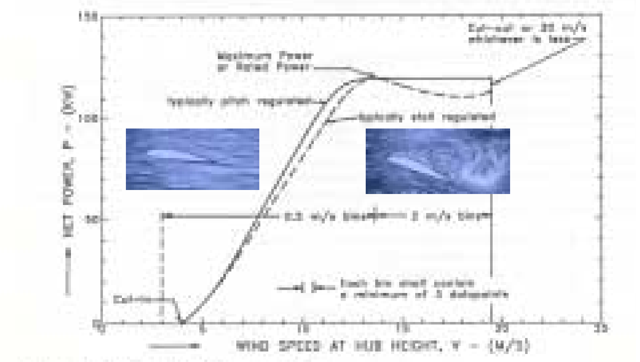

Figure 6 Power performance measurement requirements to cover power regulation wind speeds, IEA recommendation 1990

International Energy Agency IEA issued the first international recommendation on power performance measurements in 1982, and it was revised in 1990 [5]. The Americans made their own recommendation through the American Wind Energy Association in 1985 [6]. Test stations in Europe developed their own procedures, mostly based on some parts from the IEA recommendation. In 1989 they issued a European recommendation [7], based on an international cooperation and the experience of the test stations. In Denmark, however, a new certification system of wind turbines was developed in 1992, and an improved Danish power performance measurement recommendation was developed as part of the certification system [8]. The Dutch and German also developed certification systems. For the wind turbine manufacturers it was not acceptable that they had to test their wind turbines and have them certified in each country. It therefore became evident that the wind energy sector needed international standards. The development of standards then started within the IEC (International Electrotechnical Commission) in the Technical Committee TC88 1991. In 1992 a working group was set up to make an international power performance measurement standard, and this was issued in 1998 [9], the IEC 61400-12.

4. THE IEC INTERNATIONAL STANDARDS

The work on the international IEC standards was quite ambitious in the 1990'ies. Some concern whether the standard proposals were based on solid foundation lead to the establishment of a European research project called European Wind Turbine Standards [10]. Six European test station partners took part in the project. Regarding measurements, the project focused on wind speed measurements, site calibration, mechanical load measurements and an electrical power quality measurement procedure. Finally, the project also included the establishment of a network of measurement institutes in wind energy. The network was called MEASNET, and the purpose was to assure harmonized measurement procedures between the European institutes. The project was continued by a European Wind Turbine Standards project no. 2 [11]. Regarding measurements it considered power performance in complex terrain and requirements for site evaluation.

The establishment of the network MEASNET was a great success. The network succeeded in establishing a common interpretation of the standards, and recognized the need of making fast recommendations in cases where international standards or recommendations would have interpretation problems. The MEASNET network established requirements for applicants to the network, and established regular inter calibration and Round Robin tests to assure that members comply with high quality demands in measurements. The network is also being used as a platform for initiation of research projects relevant for the organization. The network started as a European network, but it has now become an independent organization and the first non-European members are about to join the organization. The testing procedures, which are covered by the MEASNET organization at present, are power performance measurements, cup anemometer calibration, power quality measurements and noise measurements. For these types of measurements regular Round Robin conformity tests are made. The institutes at the establishment were DEWI Germany, Risø Denmark, ECN Netherlands, CRES Greece, CIEMAT Spain, NEL Scotland.

The early wind turbine concepts sometimes had severe problems, which caused a lot of damage to the equipment, as for instance shown in figure 7. The reason was often run-aways with high overspeeding and overloading of the rotor as the result. Requirements for the wind turbine constructions to avoid these problems, and testing procedures to verify the requirements were needed. Requirements for air brakes and procedures for testing the capacity of air brakes were developed in a Danish requirement for basis function tests [12]. Blade load testing started with sand bags. Today, the blade tests continue as full size blade tests as well as coupon tests and design detail tests. Full size blade tests are made both with static loads and fatigue loads, and both types of tests are made in edgewise and flapwise directions. In figure 8 you see a view of the Risø test facility with a blade in edgewise fatigue test.

The IEC has come far in developing standards for the wind energy sector. In 2001 an IEC system for Conformity Testing and Certification of wind turbines was issued [14]. This standard refers to a number of other standards under Technical Committee 88 [15-21].

Figure 7 Safety and structural integrity are important in the design and detailed testing is a necessity

Figure 8 Edgewise fatigue testing of a full blade at the Risø test facility

These IEC standards cover design and safety standards as well as testing standards. TC88 is revising several of these standards at present, and some new standards are planned for the future [22-24]. Twenty one member countries worldwide are participating in development of the IEC standards under TC88 and nine member countries have observer status.

5. SOME BASIC METROLOGY CONSIDERATIONS

Some of the changes in the power performance standard [17] are connected to more basic metrology. It concerns the most important measurement parameter, the wind speed measurement. The standard IEC61400-121 [23] will hopefully include issues of a more precise definition of the measured wind speed, and inclusion of annexes on cup anemometer calibration procedures, classification of cup anemometers and instrument mounting procedures. The reason to take wind speed measurements so serious is the fact that just a few per cent in difference in wind speed means a lot to a multi MW installation. Often power curves are guaranteed to a level above a 95% limit, and every percent in accuracy of sensors and measurement procedure is therefore very important. The penalty fees for being below the guaranteed limit may be several percent of the total project costs.

Field comparison of wind tunnel calibrated cup anemometers have shown up to 4-5% difference in flat terrain [25]. The differences have been discovered to be due to a vague or non-existent definition of measured wind speed and different operational characteristics of the individual cup anemometers. The definition issue has been discussed the last years. Two definitions have been considered. One is the average length of the wind vector. The other is the average length of only the horizontal part of the wind vector. The resulting difference between these definitions is 1-2% dependent on turbulence level. The prevailing definition is the use of the horizontal wind speed. This is due to the fact that wind turbines in average only see two of the turbulence components. The turbulence component along the blade is not influencing performance. This definition also gives more consistent power curves in different types of terrain because wind turbines react more to horizontal winds than to the wind vector in a sloped terrain.

The difference in characteristics of the cup anemometers is in general based on characteristics in angular response, aerodynamic torque and friction torque. A classification of cup anemometers based on evaluation of these basic characteristics for specific ranges of external influence parameters is proposed for the revision of the power performance standard [23]. Table 1 shows influence parameter ranges of an A class connected to flat terrain measurements.

Table 1 Influence parameter ranges (based on 10min averages) of Class A cup anemometer classification

	Class A	
	Min	Max
Wind speed range to cover [m/s]	4	16
Turbulence intensity	0,03	0,12+0,48/V
Turbulence structure $\sigma_u/\sigma_v/\sigma_w$.	1/0,8/0,5 (non-isotropic turbulence)	
Turbulence length scale L_k [m]	100	2000
Air temp. [°C]	0	40
Air density [kg/m^3]	0,9	1,35
Average flow inclination angle [°]	-5	5

Angular response characteristics must be measured in wind tunnel as you see on figure 9, where the cup anemometer is tilted back and forth. Results are shown for three different wind speeds.

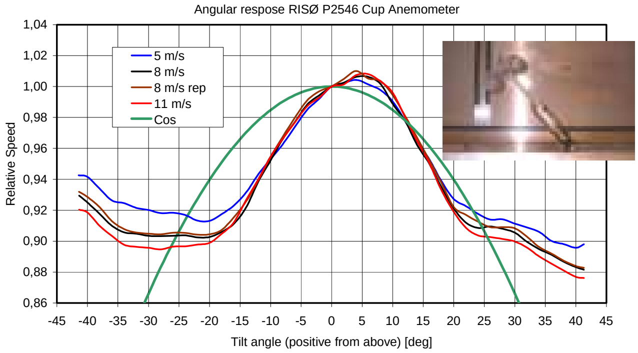

Figure 9 Tilt response measurements in a wind tunnel on a cup anemometer

The torque characteristics can be measured in wind tunnel as well. The torque is measured for instance by putting a pin on the rotor and to force the rotor to rotate at non-equilibrium speed ratios, and measure the reaction torque on the pin. The torque characteristics are important for evaluation of the so-called overspeeding effect.

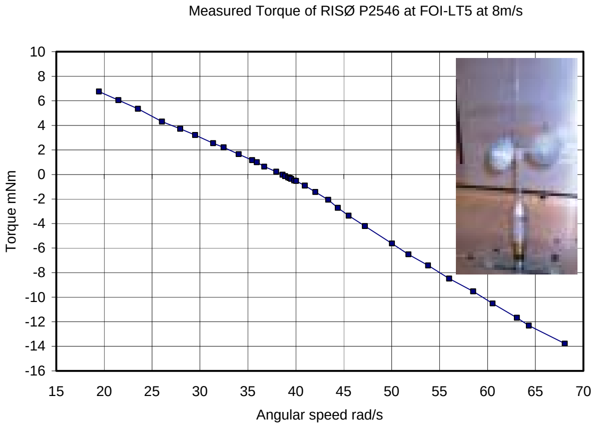

Figure 10 Rotor torque measurements in wind tunnel on a cup anemometer

The friction torque of the cup anemometer can be made by a flywheel test in a climate chamber. The rotor is substituted with a flywheel, on which the deceleration is measured. Here is an example of friction measurements where a sudden increase in friction below -5degC in encountered.

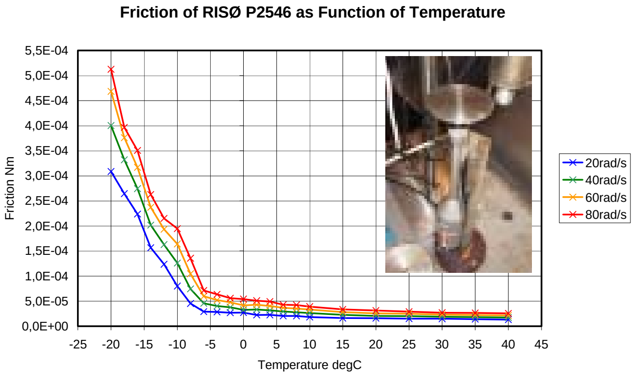

Figure 11 Friction torque measurements in climate chamber with a flywheel test method

The result of an evaluation is a classification number. As an example figure 12 shows an evaluation that results in a class 2 cup anemometer.

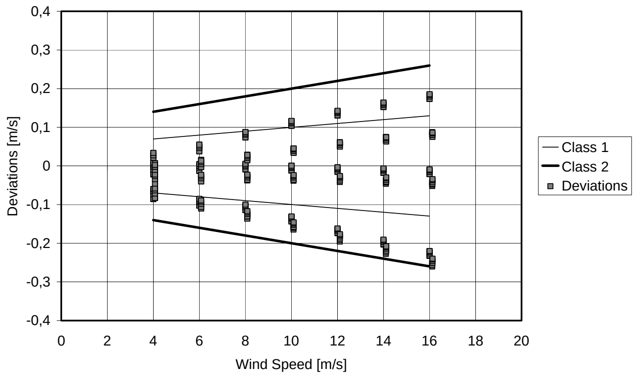

Figure 12 Cup anemometer evaluation that results in a class 2A

6. IDEAL SITE TESTING

The difficulties of making accurate wind speed measurements in complex terrain, where also the wind shear might be very difficult to verify have forced measurements on prototype wind turbines to be made at flat and ideal test sites. The advantages are many. It makes sense still to measure only wind speed accurately at hub height. The wind shear is important on large wind turbines, but the wind shear might be measured "ones and for all". As the terrain is flat the flow over the terrain is also well-defined and terrain influence on the loads on the wind turbine are very small. High accuracy can be made in the measurements and there will be a more precise feed-back to guide design and development.

In Denmark Risø has established such a test site at the west coast of the peninsula Jutland. This site has some of the best wind resources in Denmark and topography variations are below 5m.

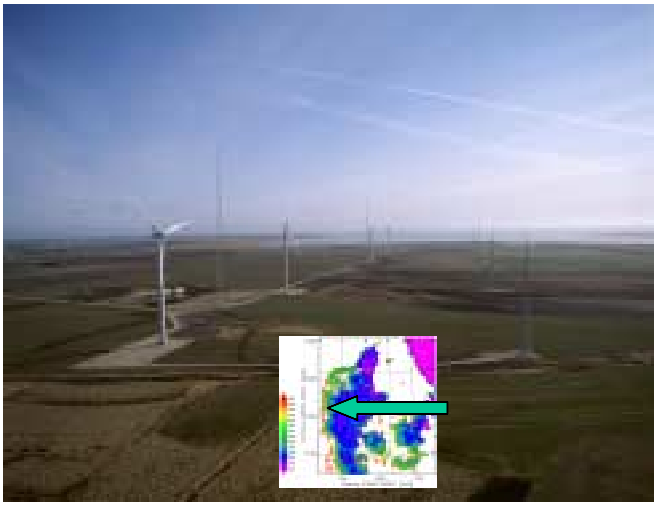

Figure 13 Danish test site of MW wind turbines at Høvsøre, western Jutland

The arrow on the wind resource map of Denmark shows the position of the test site. The test site has 5 test pads and in front of each test pad there is positioned a meteorology mast. Additionally, there is a stationary meteorology mast to measure continuously the wind shear and other meteorological parameters. Testing of large wind turbines at a test site also has some disadvantages. It is required to have lighting on top of all masts and wind turbines. Additionally, it was a requirement from the defense ministry that two masts of each 165m should be erected to have lighting to avoid collision with airplanes.

7. NEW CHALLENGING METHODS OF WIND SPEED MEASUREMENT

The cost of tall masts is very high. The two masts of 165m costs each about 300.000US$. Therefore, other types of wind speed measurements without the use of masts are being evaluated. Commercial sodars are being compared with meteorology masts and being evaluated for their applicability in wind energy as shown in figure 14.

Figure 14 Comparison of sodar measurements with stationary mast (Re. Ioannis Antoniou, Risø)

A new type of sodar is being developed at Risø. Instead of transmitting and receiving the sound at the same place, a receiver is positioned away from the transmitter. The bi-static sodar has in theory some advantages to the mono-static sodars.

Lasers provide another potential for wind speed measurements, which might revolutionize wind turbine control monitoring, and power performance verification, as shown in figure 16, but their application is on a very preliminary stage.

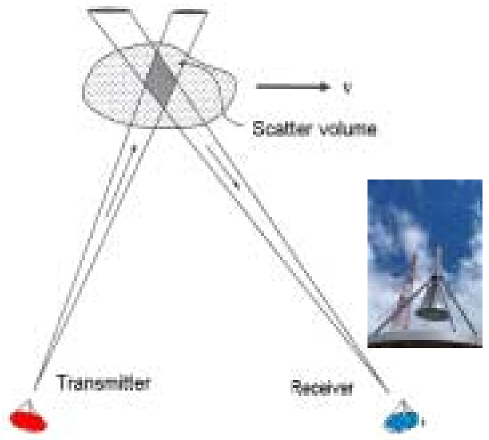

Figure 15 Bi-static sodar with transmitter and receiver separated by a certain distance on the ground (Re. Torben Mikkelsen, Risø)

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Figure 16 Laser anemometer being used on wind turbine nacelle for control and power performance verification purposes (Re. Rene Skov Hansen, Risø)

8. CONCLUSIONS

Shortly it can be concluded that:

- Wind energy will take a strong role in the electricity production in this century with a high increase the coming decades.
- Average size of installed wind turbines are at present about 1MW and increasing

- International standards for the wind energy sector have reached a high level, and several standards are now in a revision stage
- Wind speed measurements in the atmosphere are very import to the wind energy sector but are difficult and need special attention
- New methods of wind speed measurements are being introduced in the coming years and this might lead to new testing methodologies

9. AKNOWLEDGEMENTS

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