# Reliability of offshore turbines – identifying risks by onshore experience

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**Abstract –** Concerning the reliability of onshore wind turbines (WTs) a variety of monitoring programmes in several countries has gathered valuable experiences. Offshore wind energy will face additional challenges due to site-specific conditions. It is imperative that risks recognised with onshore wind energy use attract attention for the upcoming offshore challenges.

The contribution presents findings about onshore experiences concerning reliability of WTs and subassemblies with regard to an offshore use. Furthermore, an outlook about gathering and evaluating future operational experiences of offshore wind farms will be given.

## I. Introduction

Modern onshore wind turbines achieve a quite high availability of about 95% to 99% [1]. Nevertheless, quite a number of faults cause unscheduled down times, up to ten per year as average for specific wind turbine types, resulting in high maintenance efforts, production losses, and costs. Reliability achieved is therefore not satisfying and a drop of availability for offshore applications is expected by many parties. From Figure 1 it is clear that first experience with offshore wind energy use has confirmed these concerns. Obviously, the availability of existing offshore wind projects needs to be decisively improved [2, 3].

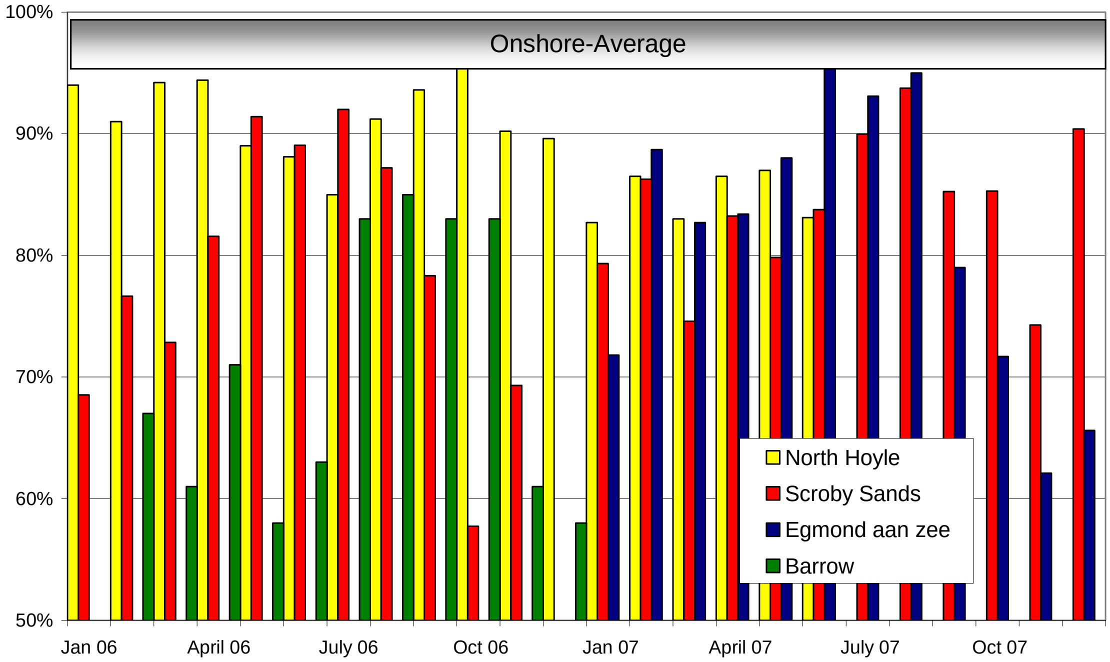

**Figure 1: Availability offshore**

To increase availability of offshore WTs it is necessary to use general findings from onshore experiences for identifying problems which can boost offshore.

The value of experience gained is illustrated in Figure 2. The mean annual failure rate depending on the year of operation and the year of production can be seen in this graph. It is clear that WTs from the first production year show the highest failure rate in the first operating year (first serial production, not first prototype). WTs from subsequent production years were able to benefit from the experience gained from previous production years.

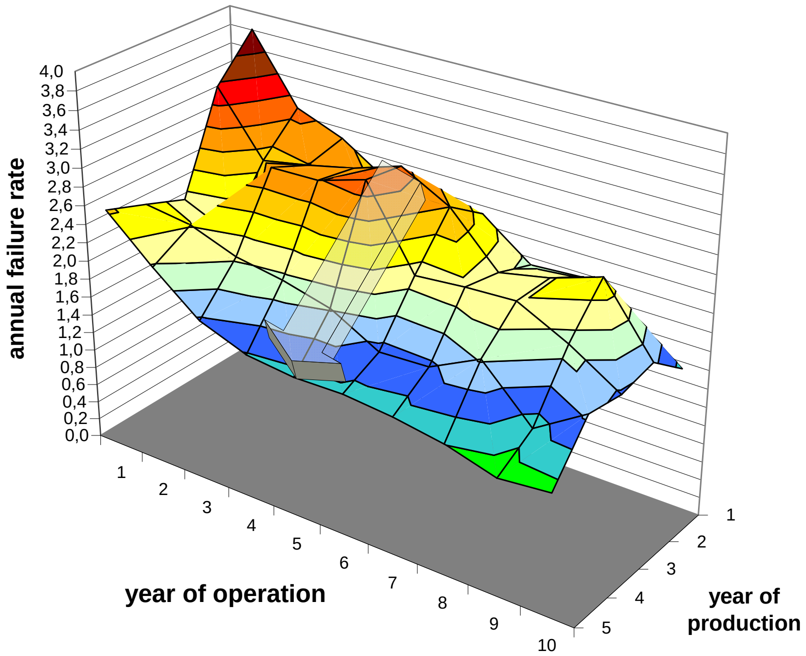

**Figure 2:** **Failure rate as a function of time**

With increasing experience both, in production and in operation, the failure rate decreases and the reliability increases respectively [4].
Another point that can be seen in this figure is the first risk regarding offshore wind energy use. It underlines the thesis that only well proven technology should be used in the offshore sector.

## II. Failure statistics

The most famous failure statistic of wind turbines has been established in the scientific measurement and evaluation programme "WMEP" ("Wissenschaftliches Mess- und Evaluierungsprogramm"), included in the German subsidy measure „250 MW Wind" [5, 6]. The resulting data base contains a quantity of detailed information about reliability and availability of WTs. It provides the most comprehensive study of the long-term behaviour of WTs worldwide and the most reliable characteristic values concerning reliability. Nevertheless, besides this data base other publicly available sources of experiences do exist. Table 1 gives an overview of some existing failure statistics.

**Table 1:** **Failure statistics**

| | *Country* | *Time span* | *Number of turbines* | *Turbine-Years of experience* |
|---|---|---|---|---|
| **WMEP** | Germany | 1989 – 2006 | 1500 | 15.000 |
| **LWK** | Germany | 1993 – 2006 | 241 | 5.719 |
| **Windstats** | Germany<br>Denmark | 1995 – 2004<br>1994 – 2003 | 4285<br>904 | 27.700<br>18.700 |
| **VTT** | Finnland | 2000 – 2004 | 92 | 356 |
| **Elforsk** | Sweden | 1997 – 2004 | 723 | 4.378 |

It is obvious that these data bases, which will be described briefly in the following, differ from each other in monitoring period, number, size and type of turbines, in the definition of subassemblies and failures, in the level of detail, and in the overall structure.

### *A. WMEP*

In the period from 1989 to 2006 a large monitoring programme, the scientific measurement and evaluation programme (**WMEP**), was accomplished by ISET(which is now the Fraunhofer IWES) in the funding programme „250 MW Wind“. In this period of 17 years besides others 64.000 reports on maintenance & repair from 1,500 WTs were collected and analysed [5, 6].

The acquisition of data was realized by means of a logbook for each WT with manual documentation by the operators. The logbook contains information like standard project data (e.g. technical data, location information, grid connection etc.), disruptions, malfunctions, repair and maintenance events with continual reporting after each instance, monthly figures of energy production, and consumption by regular readings of calibrated electricity meters as well as operating costs. The information was sent directly to ISET by the operators on customized forms.

### *B. LWK*

From 1993 to 2006 failure statistics were published by the Landwirtschaftskammer Schleswig-Holstein (**LWK**) [7]. The annual report contains output data and failures of all WTs in Schleswig-Holstein, a province from the northern part of Germany.

### *C. Windstats*

Windstats Newsletter is a quarterly international wind energy publication with news, reviews, and WT production and operating data from thousands of WTs [8]. Published as a supplement to Windpower Monthly, **WindStats** Newsletter often features analyses alongside the data for its readership of energy professionals. The Windstats survey covers a fraction of the WTs installed in Germany and Denmark.

### *D. VTT*

In Finland WT data are collected by **VTT**, the Technical Research Centre of Finland [9]. The data are published in an annual report (“Tuulivoiman Tuotantotilastot Vuosiraportti”) that shows the development of wind power and the performance of existing plants. It contains statistical data of performance, failures, and downtimes for wind power plants situated in Finland

### *E. Elforsk*

An annually published report from **Elforsk** (“Driftuppföljning av vindkraftverk, årsrapport”), which concerns statistical data of performance, failures and downtimes, provides information for almost all wind power plants situated in Sweden [10].

### *F. Other*

Even though they differ strongly from the surveys described above, there are two more sources of experience which deliver at least general findings:

- During 1986 and 1987 output data and failures of 290 turbines in the US state California are collected and presented by the Electric Power Research Institute (EPRI) [11].
- The „New Energy Industrial Technology Development Organization“ (NEDO) asked, in the framework of an investigation of the committee for increase in availability/capacity factor of wind turbine generator system and failure/breakdown investigation of wind turbine generator system subcommittee, wind power companies to provide information about WT failure/breakdown [12]. They recorded failures from 924 WTs, belonging to 187 wind farm operators in Japan, which occurred during 04.2004 to 03.2005. Unfortunately only failures having downtimes greater than three days have been recorded.

## III. Identified risks

Although these data bases differ from each other in terms of date and duration, of data collection, of WT types concerned, and of data structure they show at least in general similar results. The following table shows the average failure rates and the annual downtimes per WT both over the whole survey period and as an average over all WT in the survey.

**Table 2: General results**

| | *Average failure rate [failures/turbine/year] over whole survey period* | *Annual downtime [hours/turbine/year] over whole survey period* |
|---|---|---|
| **WMEP** | 2,4 | 156 |
| **LWK** | 1,9 | 27 |
| **Windstats** | 1,8<br>0,7 | 93<br>- |
| **VTT** | 1,5 | 237 |
| **Elforsk** | 0,8 | 58 |

It can be seen, that in all data sets the WTs have about one or two failures per year. Hence resulting annual downtime however shows a wider range. It varies from about one day to more than one week.

A possible explanation for the differences in the resulting annual downtimes could be found in the question, which subassemblies are affected. Since the downtime per failure strongly depends on the damaged subassembly an investigation in the distribution of failures belonging to different subassemblies is necessary. The following table gives an overview about the subassemblies with the highest failure rates and with the longest downtimes per failure for the different failure statistics.

**Table 3: Subassemblies with high failure rates and long downtimes**

| | *Highest failure rate* | *Longest downtime per failure* |
|---|---|---|
| **WMEP** | 1.Electric 2.Control 3.Sensors | 1.Gearbox 2.Drive train 3.Generator |
| **LWK** | 1.Electric 2.Rotor 3.Control | 1.Gearbox 2.Rotor 3.Electric |
| **Windstats** | 1.Rotor 2.Electric 3.Sensors<br>1.Control 2.Rotor 3.Yaw-System | 1.Gearbox 2.Rotor 3.Drive Train<br>– |
| **VTT** | 1.Hydraulic 2.Rotor 3.Gearbox | 1.Gearbox 2.Rotor 3.Support & Housing |
| **Elforsk** | 1.Electric 2.Hydraulic 3.Sensors | 1.Drive train 2. Yaw-System 3. Gearbox |

There is a substantial variation in downtimes after failures. On the one hand there are failures, which occur frequently, but can be repaired quickly and on the other hand there are some failures, which occur rarely, but cause long downtimes [13].

A division of failures according to the resulting downtime per failure is shown in Figure 3. The red line shows for logarithmic scaled groups of downtimes the corresponding share of failures while the blue line shows the share the total annual downtime for each group of downtimes.

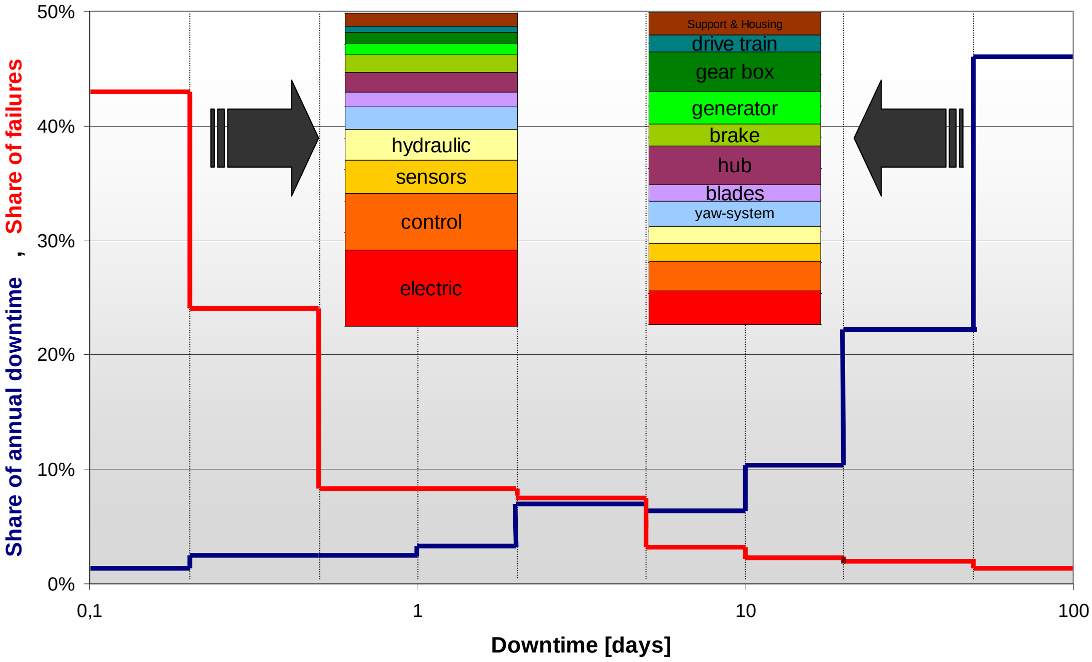

**Figure 3:** **Characteristic of failure occurrence**

As one can see the influence of the large number of short shut downs on the annual downtime is rather small. When dividing failures according to their duration in shorter or longer than one day the less severe failures, representing about 75% of all failures, are responsible for only 5% of the total downtime, whereas the remaining 25% of failures are responsible for 95% of the downtime.

These 25% of failures are spread over all subassemblies, but the components with the greatest share of annual downtime are the ones which have already been mentioned in Table 3. For a sophisticated condition based maintenance strategy these are the components which the development of condition monitoring systems (CMS) needs to concentrate on.

However, the less severe failures cause relatively little downtime, but they require considerable attention in the maintenance organisation and they cause a significant effort for repair. When WTs are installed offshore it is likely that these failures may assume more significance because they cannot be resolved quickly as access is more difficult.

The small failures and their consequences are more likely to be avoided by improving the reliability of the affected subassemblies through design improvements and reliability based maintenance.

## IV. Transferability Offshore

Wind energy technology has progressed enormously from the beginning of modern wind energy application in the middle of the 1980s until today. The continuous expansion of wind energy use has enabled manufacturers to make enormous technical progress. Amongst other indicators, this evolution can be seen in the development of rated power and complexity of technical concepts as well as in the changes according to external conditions, particularly if the WT are to be installed offshore. For both areas (turbine type and external conditions) the transferability from onshore experience to offshore use is investigated in the following.

### *A. Wind Turbine Type*

The reliability of WTs is of course strongly dependent on the WT in use. An example can be found in the size of WTs. Figure 4 shows the average failure rates for WT models in the LWK survey averaged over the 11 year period. It is obvious that larger WTs have a lower reliability [14].

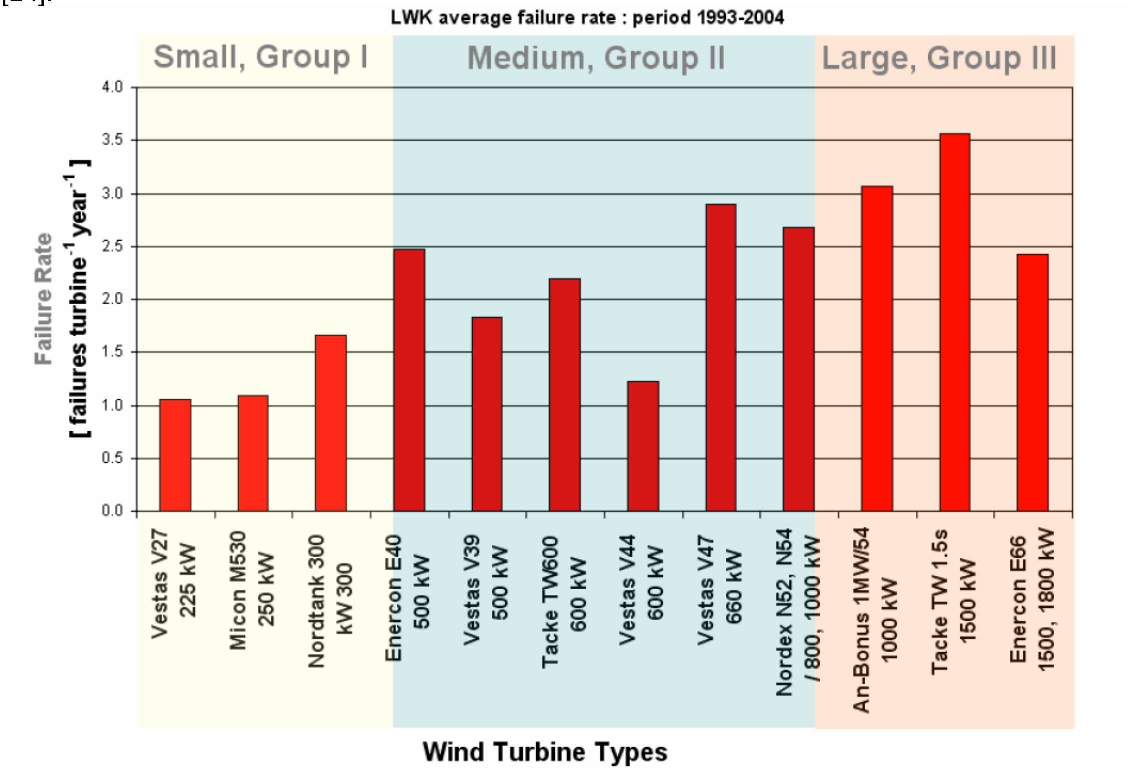

**Figure 4: Wind speed dependency of failure rates [14]**

Besides the size the technical concept of the WT is a very important influencing parameter regarding the reliability. To allow a comparative analysis different WTs from the WMEP database are classified in four groups of WT concepts [15]. An overview of the characteristic features of the concepts is given in the table below.

**Table 4: Characteristic features of the different concepts**

| | *Simple Danish concept* | *Advanced Danish concept* | *Variable-speed concept* | *Direct-drive* |
|---|---|---|---|---|
| Exemplary turbine groups ( WMEP) | AN Bonus 100/150<br>Vestas V 17/20 | Vestas V 25/27/29<br>Ventis 20-100 | Vestas V 63/66<br>Enercon E 32/33 | Enercon E 40<br>Enercon E 66 |
| Control | Stall | Pitch | | |
| Speed characteristic | Constant | | Variable | |
| Gearbox | Gearbox | | | Direct-drive |

These concepts are somehow reflecting the evolution of WT technology through time. While the performance and the efficiency of WTs, and by that the energy yields, have been improved, the reliability of WTs has decreased with ongoing development. Figure 5 summarizes the differences between the single concepts, aiming at an overall picture of development of reliability.

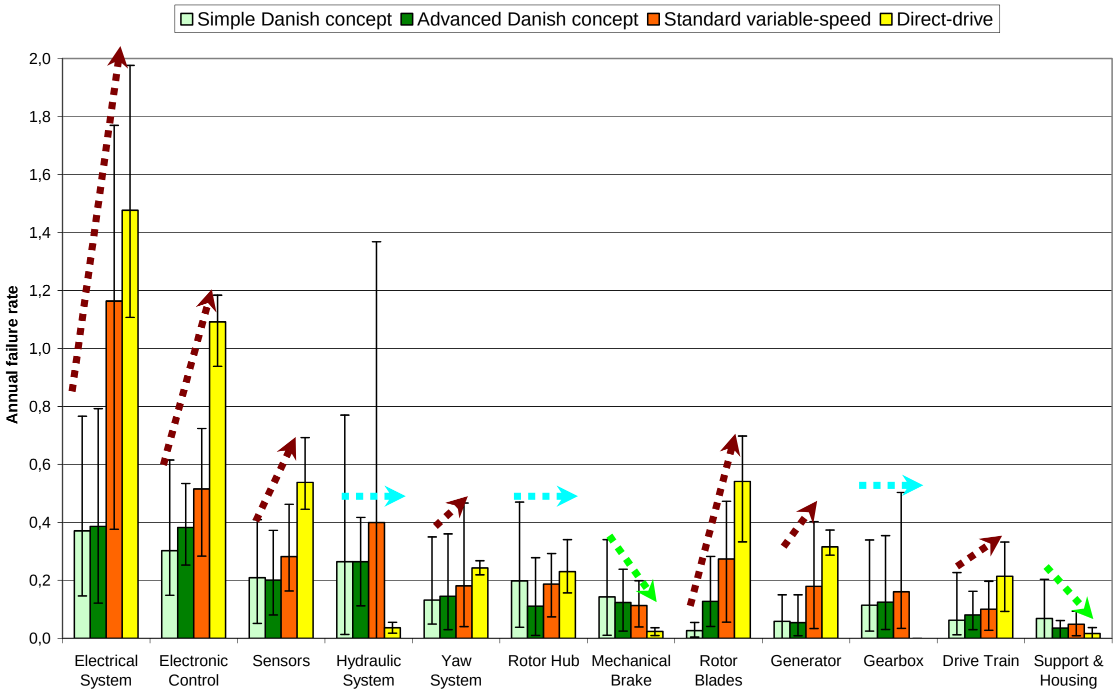

**Figure 5:** **Failure rates of different technical concepts [15]**

Trends towards a decreasing reliability can clearly be seen. For a better illustration the general trends are marked with arrows. In most cases a trend in the direction of higher failure rates can be observed. These increasing trends, which occur for the electric system, the electronic control, the sensors, the yaw system, the rotor blades, the generator, and the drive train, are shown by a dark red arrow. The only downward trends can be seen for the mechanical brake and for support & housing, labelled by the green arrows. For the other subassemblies (hydraulic system, rotor hub and gearbox) no obvious trend can be seen.

However, in the development of the technical concepts also a clear shift in the proportion of the different subassemblies can be observed. While frequent failures with short downtimes are getting more frequent, failures resulting in long downtimes are getting more seldom.

### *B. External conditions*

Besides size of WT and technical concept there are more parameters, which should be considered in an appropriate reliability analysis [16]. The influence of operational conditions is indeed important to indicate the availability characteristics of WTs. The wind speed is an example for those parameters, which was already analysed in general by [17].

The examined wind speed dependency of failure rates is shown in the following figure.

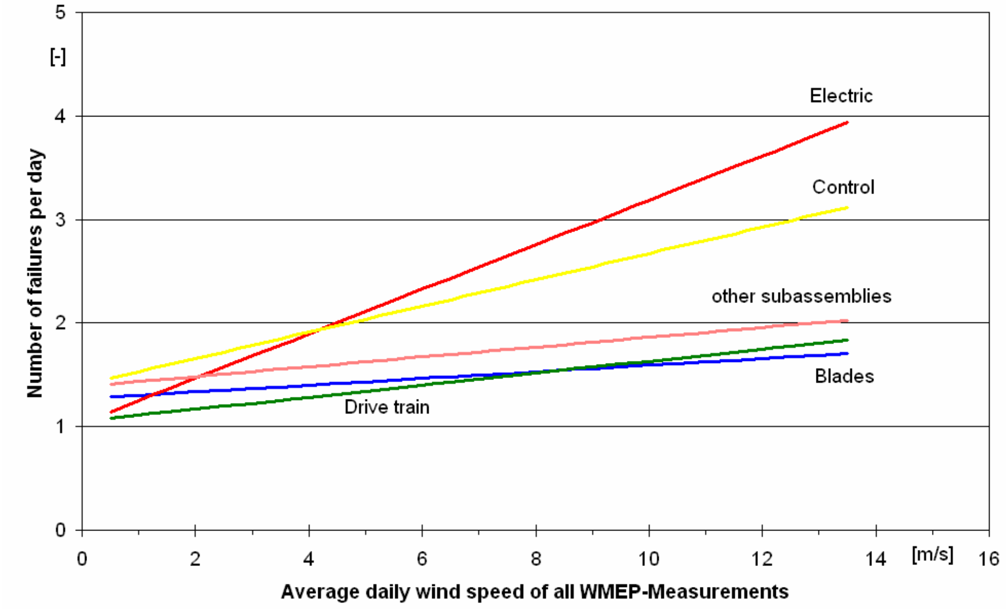

**Figure 6: Wind speed dependency of failure rates [17]**

The failure rates of subassemblies of the electrical system show the strongest dependency from wind speed. While for these subassemblies two failures occur in days with moderate wind speed (10 m) of 4 m/s, the failure occurrence increases to four a day at an average daily wind speed higher than 10 m/s.

The dependency of the failure rate on wind speed is generally also present, but significantly weaker for the other main subassemblies.

A physical check on the similarities between failure rate and wind energy index (WEI) was performed in [18]. The results are given in Figure 7. The failures in a given month throughout the period have been summed up and compared with the summed WEI in that month.

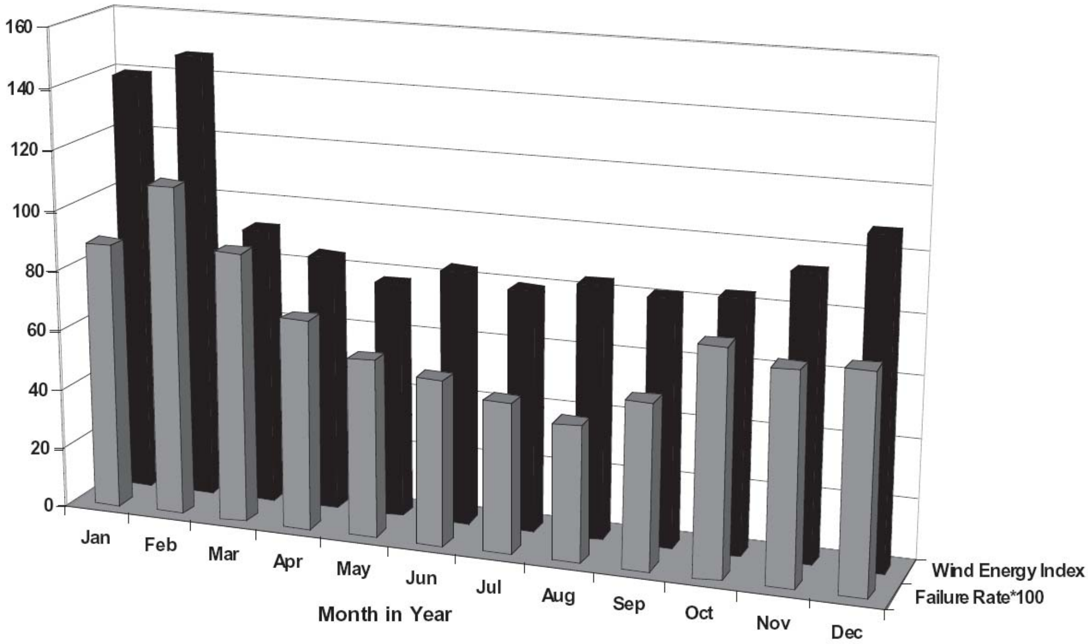

**Figure 7: Correlation between failure rate and wind energy index [18]**

It is obvious that there is a clear relationship between the failure rate of a population of Danish WTs and the Wind Energy Index averaged over Denmark.

## V. Conclusion

Reliability of WTs and subassemblies needs to get improved. Otherwise, availability, especially for offshore application, will not reach suitable results [19]. Improvements have to be achieved in the design of WTs as well as in the organisation of maintenance. Following risks for a declining availability of offshore wind farms can be derived from operational experience with onshore application:

- In many cases offshore wind farms will consist of new WT models, thus one risk is a high failure rate due to many early failures.
- A hopefully small number of severe failures will cause long downtimes. Due to more complicated repair procedures, there is a risk for prolonged downtime per failure.
- Similar to onshore application, numerous minor failures will cause many downtimes, but due to complicated access the duration of these downtimes will increase.
- Offshore application will utilise large WTs with more complex technical concepts. In the past, increasing size and complex design lead to a declining reliability. Thus there is a risk for reduced availability due to necessarily large WTs with sophisticated design for offshore application.
- WTs, especially electrical and electronic subassemblies, tend to fail more often in periods of high wind speeds. Due to the higher wind potential offshore and additional stresses through offshore conditions, the risk for failures rises.

## VI. Outlook

Although wind energy use has been established well during the recent years, still common standards for the documentation of O&M measures as well as for a uniform structure of data bases are missing. Thus, a working group of the ‘Foerdergesellschaft Windenergie’ (German association supporting the development of technical standards for wind energy use) is working on appropriate standards for the O&M of wind power plants.

Single WT operators will possibly not be able to achieve a suitable statistical basis for thorough analyses. Even with a broad data base like the one from the WMEP, the breakdown in concept groups, power classes, site conditions, etc., lead to a point, where the statistical basis was getting insufficient. The necessity for a broader data base and for an appropriate data structure is obvious [4, 16]. A joint approach of operators, firstly agreeing on standards and secondly on requirements, promises being most successful.

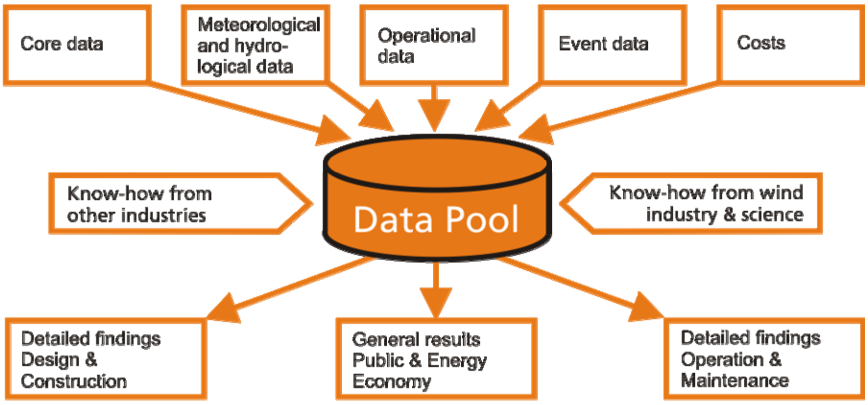

**Figure 8: Concept of the Offshore~WMEP**

Joint activities on standardising O&M measures, documentation and data structure have been launched on a national German basis for onshore wind energy application [20]. First steps have been made also for offshore wind energy use. A group of planners and operators have confirmed to support a new German programme for monitoring the development of offshore wind energy use as well as improving availability of offshore wind farms. This new project is named ‘Offshore-WMEP’ (OWMEP) following the former German monitoring programme for onshore turbines [21].

The principal concept of collecting data in a data pool, driven by a neutral and independent institution, is shown in Figure 8.

This project is currently running in a concept phase and is designated to start operation together with the first German offshore wind farms. It will enhance the data base, already existing for onshore application.

However, operators of wind farms have started to document assets, maintenance measures and failures using standardised structures. Thus, future analysis of failure rates, downtimes and causes can be based on much more detailed information and on an enhanced statistical basis.

## VII. Acknowledgements

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