Big Experience with Small Wind Turbines – 235 Small Wind Turbines and 15 Years of Operational Results

Paul Kühn

Institut für Solare Energieversorgungstechnik e.V. (ISET)
Königstor 59, D-34119 Kassel, Germany
Tel: +49(0)561-7294-351 Fax: +49(0)561-7294-260
E-mail: pkuehn@iset.uni-kassel.de

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Abstract

In comparison to large wind energy plants, small wind turbines (SWT) lead a shadowy existence today. There is a great need to acquire and share operational data of SWT systems in order to identify and overcome technical and market barriers. This paper reviews the long-term experience with SWT that has been gathered at ISET.

For more than 15 years the Scientific Monitoring and Evaluation Programme (WMEP) accompanied the development of wind energy use in Germany. The WMEP holds intensive and long-term data on plant production, reliability, economics and wind resources for more than 1,500 wind turbines (WT) including 235 SWT, that have a rotor swept area of less than 200 m^2.

This contribution focuses on the 235 SWT representing 16 different manufacturers. Although a number of the manufacturers do not exist anymore due to buying, fusion or closure, the SWT-specific analysis of the WMEP data gives valuable information about the performance of different SWT models. Furthermore the SWT are subdivided into two size categories: SWT that have a rotor diameter equal or smaller than 7 m and larger ones.

Special attention is given to the reliability of SWT with focus on technical availability, main causes of failure and affected, repaired and replaced components.

Keywords: Small Wind Turbine, Performance, Reliability, Monitoring

1. Introduction

The worldwide market for small wind turbines (SWT) has an enormous potential. Applications range from remote autonomous off-grid systems in developing countries to private grid connected SWT that are installed with the aim of reducing electricity bills. But despite their enormous potential, SWT lead a shadowy existence today. The reasons are manifold: high costs, a lack of technological maturity, insufficient testing and a complex market with a large number of small manufacturers and various technical concepts are the most important to be mentioned.

Long-term operational data of SWT is of great value. It allows the evaluation of the technical and economical performance and contributes to the optimization of design features and system configurations.
The Scientific Monitoring and Evaluation Programme (WMEP) within the "250 MW Wind" funding programme accompanied the development of wind energy use in Germany since 1989. Numerous SWT, almost exclusively connected to the grid, have been installed in Germany already in the late 1980s and early 1990s. A total of 235 SWT with a rotor swept area of less than 200 m^2 (as defined in [1]) joined the programme between 1990 and 1996, each turbine being monitored by the WMEP for at least 10 years.

The photos of SWT in the WMEP in Figure 1 show diverse technical features concerning e. g. the number of rotor blades, the yaw mechanism and the tower type. Although most of the SWT manufacturers represented in the WMEP do not exist anymore due to buying, fusion or closure, the SWT-specific analysis of the WMEP data gives valuable information about the performance of SWT with different design features. For a more detailed analysis the SWT are also subdivided into two size categories:

- Category 1: 205 SWT that have a rotor diameter between 7 m and 16 m, which is corresponding to a swept area between 40 m^2 and 200 m^2.
- Category 2: 30 SWT that have a rotor diameter equal or smaller than 7 m, which is corresponding to a swept area equal or less than 40 m^2.

The next chapter briefly discusses the development of SWT in Germany as well as economics and energy yields of SWT in the WMEP. The third chapter focuses on the reliability of SWT.

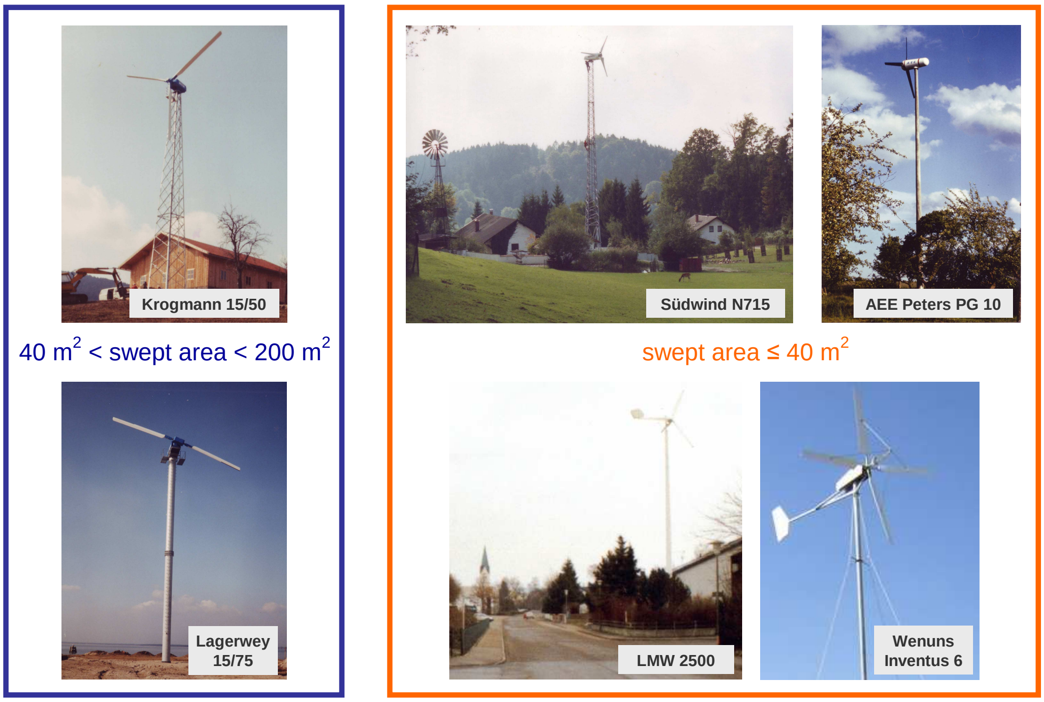

Figure 1: Examples of SWT in the WMEP – category 1 (left) and category 2 (right)

2. Development, Economics and Energy Yields

The size of WT has increased enormously since the beginning of modern wind energy application, in the middle of the 1980s. In Figure 2, the division of WT into rated power classes, and the representation of the yearly installation rate of WT in each class, shows that new models with higher power classes have quickly superseded their prevailing small predecessors [2].

WT in the power class from 1 kW to 75 kW, which mainly represent SWT (swept area less than 200 m^2) have almost exclusively been installed in the first years of the "250 MW Wind" funding programme. Since 1995 only a small number of SWT have been erected in Germany, because newer and larger WT models were more economical and efficient. The last SWT that has received funding by the "250 MW Wind" programme and has been monitored within the WMEP was installed in 1996.

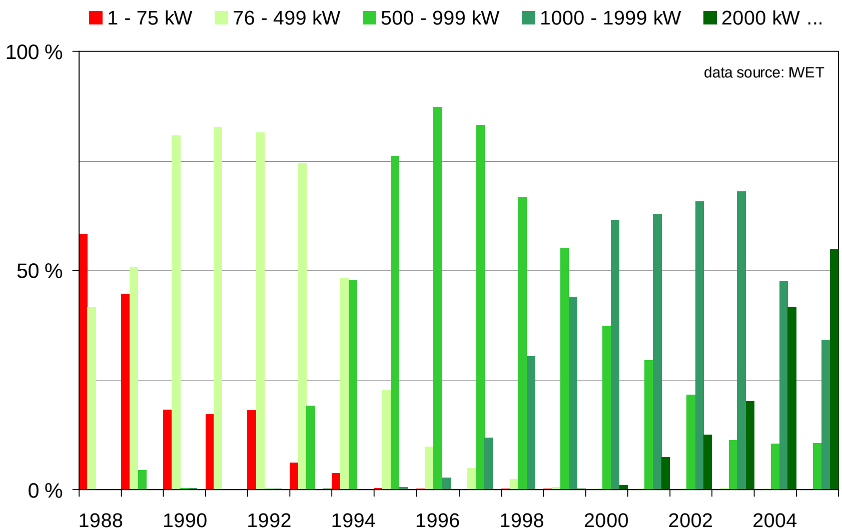

Figure 2: Share of newly installed wind turbines in Germany per power class

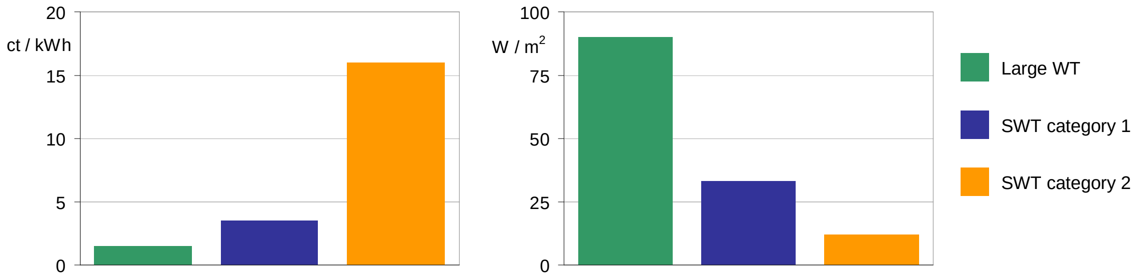

Figure 3: Operational costs (left) and specific power output (right) for large WT and SWT in the WMEP

Figure 3 exemplifies the trend towards lower specific costs per kilowatt installed power and higher specific energy yields, with increasing plant size.

The left diagram in Figure 3 shows the operational costs for large WT and SWT in the WMEP. The main expenses include costs for maintenance and repair, insurance, lease, management and personnel. The average operating costs of large WT are approximately 0,01 €/kWh to 0,02 €/kWh. Operating costs are twice as high for SWT in category 1. Here, a large proportion of the feed-in reimbursement is used for the operating costs. The average operating costs of the 30 SWT in category 2 are considerably higher and amount to about 0,16 €/kWh.
Not only are the operating costs decreasing with increasing plant size, but also the specific price of large WT has significantly been reduced by increasing production rates and optimizing production processes in the last decade.

The graph on the right hand side of Figure 3 depicts the specific power output for different plant sizes. Determining the quotient between mean power and swept area facilitates an overall comparison of the specific power output, the influence of wind resources being neglected. It becomes clear that SWT fall significantly behind larger and higher plants. Large WT in the WMEP achieve an average of 90 W/m^2, SWT in category 1 around 33 W/m^2, while SWT in category 2 only achieve 12 W/m^2.

The reasons for this are manifold. Wind turbine technology has progressed enormously in recent years, including improvements in efficiency, but the SWT in the WMEP generally represent older turbines. SWT also have lower hub heights and, in many cases, are located in the vicinity of houses or other buildings - two factors that directly affect the turbine output.

Cost reduction opportunities exist through production of SWT in large quantities and the advancement in SWT technology as has been done with large WT. In order to obtain maximum SWT performance the limited efficiency of SWT must be compensated by good siting and an adequate tower height.

Regardless their relatively high specific costs and lower efficiency, when compared to large wind energy plants, SWT have enormous potential - particularly with respect to off-grid systems. High robustness and high reliability are key requirements for a successful operation, especially in remote regions. The next chapter, therefore, comprises an analysis of the reliability of SWT in the WMEP.

3. Technical Reliability of SWT in the WMEP

Malfunctions, repairs and maintenance of SWT in the WMEP have been reported on form sheets. A total of 4 200 reports concerning maintenance and repair were submitted by SWT operators.
About 1 700 reports were related to scheduled maintenance. Out of these maintenance reports, 700 mentioned the replacement of wearing parts or the replacement of defective parts.
Another 2 500 reports were concerned with unscheduled malfunctions, which can be divided into two groups: repair (1 700 reports) and reset of the control system (800 reports).

Causes of Failure

Figure 4 shows the causes of failure for all 235 SWT in the WMEP. For 20 % of the failures the causes could not be determined or were marked as "others” on the report sheet.

Most of the reported causes for failure are based on defective parts or control system malfunctions. Combined with the failures due to loose parts, these account for 57 % of the failures. This is in the same order of magnitude as large WT, whereas external influences have a higher share for SWT totalling to about one quarter of causes for failure.

In comparison to the newer and larger wind energy plants, SWT in the WMEP are more susceptible to storms and strokes of lightning. In this sense SWT are required to become more reliable, keeping in mind that SWT applications have the biggest market potential in remote regions. In such applications, it will be more difficult to access the SWT site. Furthermore SWT must be capable to operate in extreme environmental conditions.

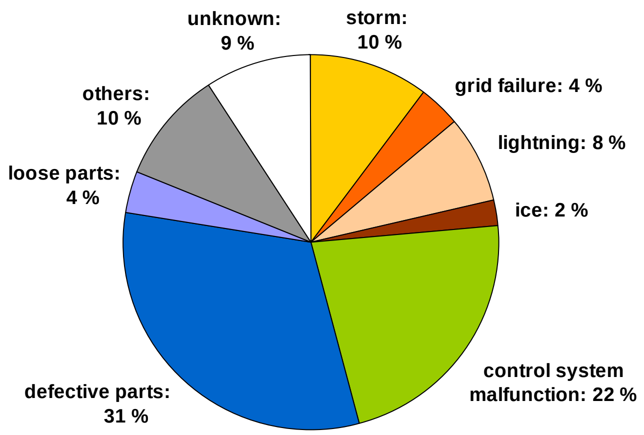

Figure 4: Frequency of causes for failure for all SWT (both categories) in the WMEP

<u>Repair and Replacement of Main Components</u>

Figure 5 depicts the breakdown of repaired components for both SWT size categories. The two pie charts illustrate that the component groups electronic control (electronic control unit, relays, measurement cables and connections) and electrical system (inverter, fuses, switches, cables/connections) are susceptible to failure. These two groups are also the most affected in large wind energy plants.

Generally about half of the repairs of large WT are concerned with electrical, the other half with mechanical components. For SWT in category 1 this ratio is slightly shifted to 60 % electrical (blue) and 40 % mechanical components (brown), while for SWT in category 2 it is the other way round. Moreover, concerning SWT in category 2, the mechanical component group rotor hub (hub body, pitch mechanism, pitch bearings) accounts for 23 % of all repairs.

Nowadays active pitch control is a common feature of large WT. The majority of SWT in the WMEP are already pitch controlled too. However, this feature proves to be less reliable. Particularly the 24 out of the 30 SWT in category 2 that have a passive pitch mechanism require more frequent repairs.

The replacement of a main component is a good indicator to assess the long-term reliability of the SWT as it usually implies very severe damage.
Only six replacement measures were documented for a total of five SWT in category 2.
Yet for every third SWT in category 1 at least one main component had to be replaced. A closer look reveals that out of the 132 replacement measures in category 1 almost 100 components were concerned with only two specific turbine models. These design faults resulted in the replacement of 27 generators, 34 sets of rotor blades and 20 rotor hubs. The costs of replacements were in most cases covered by the two manufacturers involved.

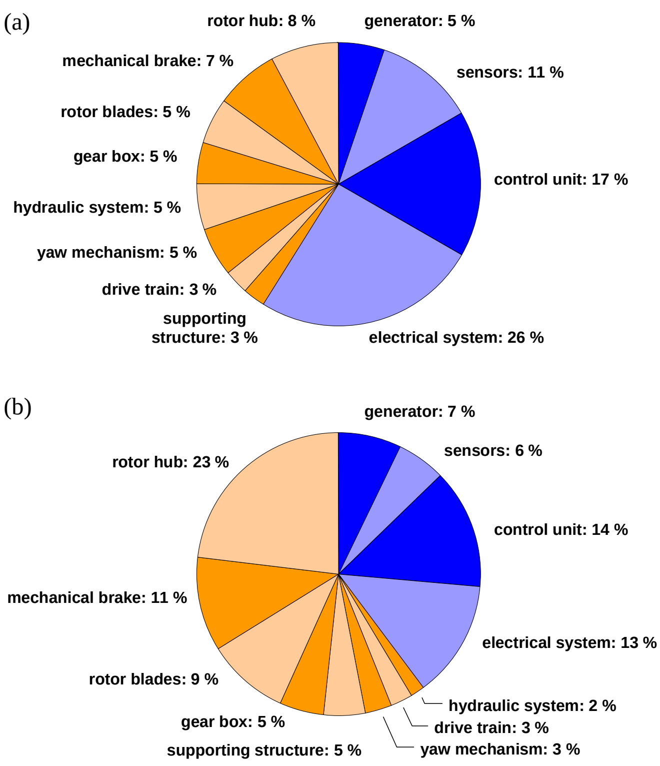

Figure 5: Share of repair measures on components for SWT category 1 (a) and category 2 (b)

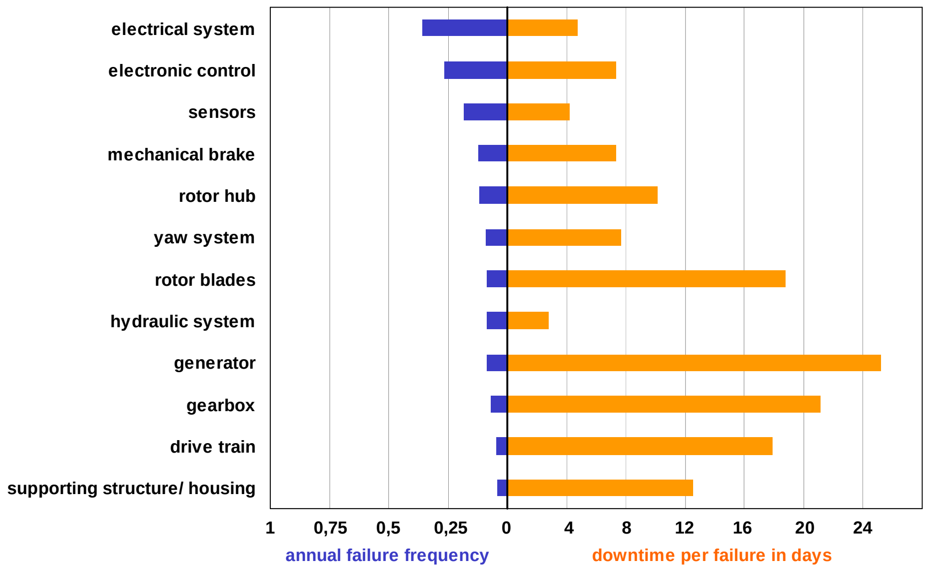

Figure 6: Frequency of failure of main components and related downtime for all SWT (both categories) in the WMEP

<u>Reliability, Failure Rates and Downtimes</u>

With respect to the overall annual failure rate, SWT can be considered more reliable than large wind energy plants in the WMEP, whereby large WT have one to four failures per year, depending on size and type.

SWT in category 1 have on average less than one failure per year and SWT in category 2 only about one failure every two years. A trend towards more frequent failure of SWT with increasing plant age has not been noted. Data for SWT exceeding 10 years in age is insufficient to make statements about the reliability of these older turbines and their actual life expectancy.

Out of the 235 SWT in the WMEP 14 SWT had a lifetime of only between five and nine years. The close-down of these turbines were caused by e. g. lightning, fire, rotor over-speed and collapse of the tower. At least another 14 SWT closed down before attaining 10 years of operation. Among other reasons these SWT had damages that were too expensive to repair or technical inspection authorities decided that the turbines were no longer safe to operate.

The reliability of SWT and their components is not only measured by the frequency of failure, but also by the time required to return to functional operation. Reports concerning repair measures do not only relate to individual components, as simultaneous repairs to a number of components are often necessary. The periods of downtime shown in Figure 6 are somewhat unclear due to the possible double entries [3].

It becomes apparent that the more frequent faults e. g. in the electrical system, electronic control and sensors, require less effort and time to fix than to repair or replace a large component like rotor blades, generator or gearbox. As an example: In a purely statistical analysis a failure in the electrical system occurs once in three years and takes four days to repair, while a fault in the generator occurs only once in 12 years but takes more than three weeks to repair.

By contrast the relatively frequent failures of large WT are usually repaired within one or two days, the more seldom ones of large components in less than seven days. Thus, in comparison to large WT the downtimes of SWT are very long. The limited service capacities of the SWT manufacturers and the comparatively low production losses account to some extent to the longer downtimes.

But the very long downtimes due to the breakdown of larger components cannot be completely explained by this. The average of almost 25 days downtime in case of a failure of the generator originates from stand stills that were caused by repeated problems of mainly six SWT models. These include the SWT model with the design fault of the generator for which about every second generator had to be replaced (see previous page). In many cases the combination of limited capacity of trained service personnel and non-availability of spare parts or spare components caused the long downtimes. This problem concerns particularly very small manufacturers that have only little resources and few employees.

Large WT have an overall technical availability of about 97 % to 98 %. Although SWT in the WMEP have a lower failure frequency, the longer downtimes per failure result in an average technical availability of about 96 %.

4. Conclusions and Outlook

The evaluations of long-term operational data of more than 200 SWT prove that it is more economical and efficient to use large WT for grid connection in Germany. However, SWT have an enormous potential in other applications, particularly in off-grid power supply systems and isolated small grids in rural regions of developing countries. In such remote applications a high technical availability of SWT is crucial to provide the needed security of supply.

The WMEP evaluations on reliability show a promising low frequency of failure for SWT. Though the use of more complex design features generally result in an impairment of reliability. In order to facilitate short downtimes and a high technical availability, easy maintenance and repair are key requirements. Further development and optimization of SWT as well as system integration of SWT into autonomous power supply systems are therefore important research areas at ISET. One approach is to use the most simple turbine design possible, which means accepting a lower efficiency but at the same time reducing costs, increasing reliability and improving serviceability and maintainability.

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