Introduction to Small Wind Turbines

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Introduction

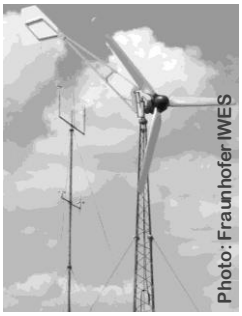
In the last two decades wind power utilization has emerged from a niche industry to an industrial sector with global significance. According to the World Wind Energy Association (WWEA) the worldwide capacity of installed wind power reached 160 GW by the end of 2009. In the same year the worldwide wind sector had a turnover of 50 billion Euro and employed 550 000 persons [1].

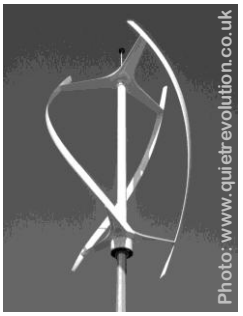
In the mid 1980s, wind turbines had an average rated power of 30 kW and rotor diameters of less than 15 m. Since then, wind turbines with a rated power of 5 MW and more and rotor diameters of more than 125 m have been developed. Today, multi-megawatt wind turbines of 2 MW and more dominate the market. But in the last few years the interest in small wind turbines has also grown again. Small wind turbines are used in a broad field of application ranging from very small mobile battery chargers rated at only a few hundred watts to grid-connected systems with 30 kilowatt and more. In addition there is an enormous untapped potential for small wind turbines to be applied in rural regions and developing countries, in off-grid power supply systems and mini-grids.

This introductory contribution is intended to provide an overview of small wind turbine classification options and an insight into the current market situation of available small wind systems. Finally product specifications of small wind turbines are briefly discussed and planning considerations of small wind systems and PV systems are contrasted with one another.

1. Small wind turbine classification

Figure 1 depicts four examples of available small wind turbine models of different size and design used for different applications. But ‘How big are small wind turbines?’ and what are other options exist to classify small wind turbines?





Model	Superwind 350	Fortis Montana	Quietrevolution qr5	Hannevind 30 kW
Rotor diameter	1,2 m	5 m	3,1 m x 5 m	13 m
Rotor axis	horizontal	horizontal	vertical	horizontal
Rotor swept area	1,1 m^2	19,6 m^2	15,5 m^2	133 m^2
Rated power	0,35 kW	5 kW	6 kW	30 kW
Type of generator	permanent magnet	permanent magnet	permanent magnet	induction
Tower head weight	11, 5 kg	230 kg	450 kg	950 kg
Typical application	remote, mobile, battery charger	on- or off-grid,	building mounted, on-grid	commercial, on-grid

Figure 1: Specifications of small wind turbines models of different size and design

Table 1 shows the definitions and classifications of small wind turbines of different institutions. The most common parameters for classification are the physical size, i. e. the rotor diameter or the rotor swept area and electrical properties, i. e. the rated electrical power. The upper limit of the rated power used for small wind turbines classification shown in the table range from 50 kW to 150 kW.

Table 1: Definitions of small wind turbines by different institutions

American Wind Energy Association (AWEA) [2]	Rated capacity of 100 kW and under • Residential systems: 1 kW to 10 kW • Commercial systems: 21 kW to 100 kW
British Wind Energy Association (BWEA) [3]	Rated capacity < 50 kW • Micro-wind turbines: rotor diameter less than 2,1 m (swept area less than 3,5 m^2), tend to be either free-standing or mounted directly to the side or top of the attached building, usually mounted 3 m to 4 m above the ridge line of the attached building, or up to approx. 16 m for free-standing systems • Small-wind turbines: rotor diameter more than 2,1 m (swept area more than 3,5 m^2), predominately free-standing, although interest in mounting units on top of large residential and commercial building is growing, can reach over 30 m in total height
German Wind Energy Association (BWE) [4]	Rated capacity up to 100 kW • Residential systems: up to 30 kW
IEC 61400-2 [5]	Rotor swept area smaller than 200 m^2, generating at a voltage below 1 000 V a.c. or 1 500 V d.c. • for turbines with a rotor swept area less than 2 m^2, the tower is not considered part of the design • for turbines with a rotor swept area greater than or equal 40 m^2, there shall be a manual shutdown button and shutdown procedures • standard turbine classes defined in terms of wind speed and turbulence to cover most applications and external conditions
IEC 61400-11 [6]	Hub height less than or equal to 30 m and a maximum power less than or equal to 150 kW

Although different opinions about the size of small wind turbines exist, the definition used in the international standard 'IEC 61400-2: Design requirements for small wind turbines' [5] is widely accepted to describe the maximum size of a small wind turbine. The standard applies for wind turbines with a rotor swept area smaller than 200 m^2. This corresponds to:

Rotor swept area: $A \leq 200\ m^2$
Rotor diameter: $D \leq 16\ m$
Electrical power: P up to about 75 kW

Furthermore, it is often useful to distinguish between larger (commercial) and smaller (residential) systems. Another way to classify small wind systems is by their:

- Application: e. g. battery charger, grid-tied systems
- Site: e. g. free-standing, building mounted
- Design: e. g. rotor axis (horizontal or vertical), drag or lift machines

2. Market

The market for small wind turbines is complex and offers a great variety of models with different technical concepts. For lack of information, the current world small wind market situation can only be estimated. But latest national market reports lead to the conclusion that the biggest markets are the US, the UK and China. The vast majority of small wind systems worldwide is produced and deployed in these three countries.

According to the American Wind Energy Association (AWEA) 10 500 small wind turbines with a cumulative installed capacity of 17,3 MW were installed in the US in 2008 [2]. Since 2005, about the same number of small wind systems have been deployed in the UK, adding to a cumulative capacity of almost 6 MW (British Wind Energy Association (BWEA) [3]). And in China, about 400 000 small wind systems have been installed by the end of 2009. Another 150 000 small wind turbines have been exported from China within the last five years [7].

Figure 2 shows that about 75 % of all small wind turbines sold in 2008 were sold for off-grid applications. These units were predominantly of very small size of 5 kW rated power and less. That is why off-grid systems contributed to less than 25 % of the total capacity sold in 2008.

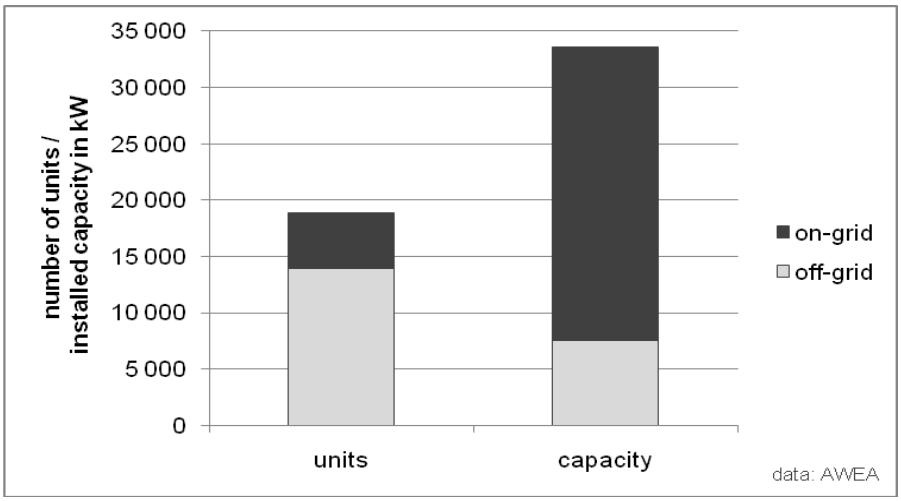


Figure 2: World small wind turbine market 2008, data source [2]

In the following a summary of current trends of the small wind turbine market is presented. The summary is based on a small wind turbine manufacturer's survey performed by IWES in 2009 (41 manufacturers participated, [8]) as well as on the latest market reports of AWEA and BWEA [2], [3]:

- Markets: the top small wind markets are North America, Europe and China, the number of installations in South America, Africa and Asia (except China and Japan) is comparatively small
- Number of units: small, purely off-grid systems of 1 kW rated power and less, outnumber larger systems
- Capacity: on-grid systems dominate the market in terms of installed capacity, with the trend of an increase of grid-connected systems having a rated power between 2 kW and 10 kW
- Design: freestanding turbines with a horizontal axis and three rotor blades dominate the market, whereas the market share of building mounted systems, often turbines with a vertical rotor axis, is rather small
- Manufacturers: the majority of small wind turbine manufacturers are small companies and in most cases offer two models or more of different size. Many manufacturers cooperate with suppliers in terms of production (e. g. blades, tower and inverter) as well as in terms of distribution and sales.

- Costs: installation costs vary from about 2 500 € to 7 000 € per installed kilowatt rated power. The wide cost range results from the great variety of available small wind turbine designs and applications, from different system sizes, from different manufacturer backgrounds and different manufacturing economies of scale.

3. Small wind turbine specifications and planning considerations

IWES investigations show that there are more than 180 manufacturers of small wind turbines worldwide. The AWEA identified at least 219 companies that manufacture, or plan to manufacture small wind turbines in the world [2].

The numerous manufacturers offer a great variety of small wind turbine models. But they also provide heterogeneous product information that makes a comparison of different small wind systems difficult. For example, there is no internationally agreed definition for rated power, i. e. at which wind speed a small wind turbine is to be rated. The AWEA recently introduced a standard that defines the rated power as the power output at a wind speed of 11 m/s [9].

In the diagrams of Figure 3 data of about 100 small wind turbines, having a rated power of up to 20 kW, are presented. The data used in both diagrams were taken from manufacturers' web sites, catalogues and data sheets.

Figure 3 (a) depicts the rated wind speeds of different small wind turbine models. It shows a wide scattering of points for the rated wind speeds, with values mainly between 9 m/s and 14 m/s. Moreover, it shows the trend for vertical axis turbines to be rated at higher wind speeds than horizontal axis turbines. Because of the broad range of rated wind speeds, it is difficult to compare the size of small wind turbine by their rated power only. The rotor size, measured by the rotor swept area or rotor diameter, is the better choice for comparing the size.

However, even a comparison of the power characteristics of small wind turbines of similar size can be quite difficult, if one only relies on the specifications provided by the manufacturer. This can be illustrated by Figure 3 (b). It depicts small wind turbine power coefficients at 9 m/s wind speed over the rotor diameter. The scattering of

points can be explained by a number of reasons including different technical concepts, turbine designs having different efficiencies of rotor, generator, and gearbox as well as insufficient test data and inconsistent and incorrect methods to measure the power curve.

Besides the large range of power coefficients, some turbine data, particularly data of smaller machines with less than 5 m rotor diameter, show inconsistent values, with a few power coefficients even exceeding the Betz limit[1].

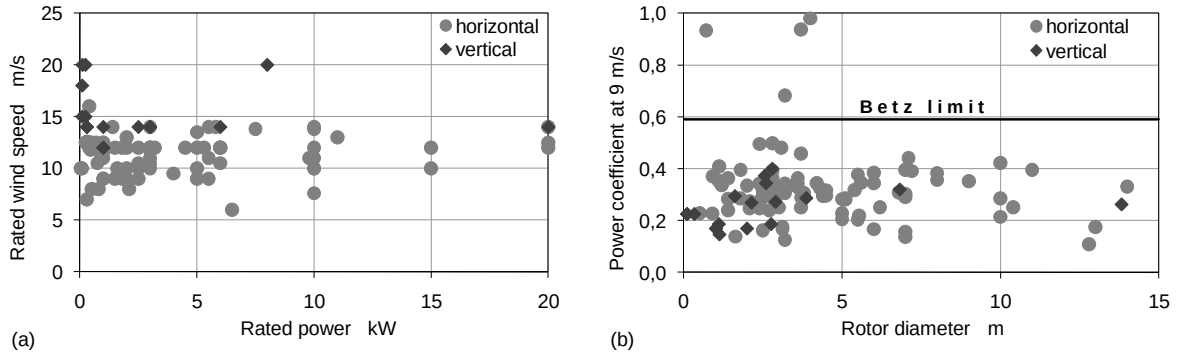


Figure 3: Specifications of about 100 small wind turbines: (a) rated power and corresponding rated wind speeds (b) power coefficients at a wind speed of 9 m/s

Besides the inconsistent product information, the developer of a small wind turbine project is also confronted with a complex small wind turbine market offering a great variety of technical concepts of varying quality. Table 2 indicates that it is generally a more complex task to plan, install and operate a small wind system than a PV-system. However, the technical and economical success of both system types, based on wind or solar energy, depends on how well the aspects in Table 2 are understood and investigated.

[1] The theoretical maximum power coefficient is called Betz limit. It is the theoretical maximum fraction of the power in the wind to be utilized by a wind turbine and has a value of 16/27 (0,593).

Table 2: Key tasks and relevant considerations when planning photovoltaic and small wind turbine systems

Task	Photovoltaic system	Small wind turbine
Resource assessment	solar radiation	average wind speed, main wind direction, turbulence, wind shear
Siting	module orientation and inclination angle, shadowing effects are visible	positioning of tower, effects (wind shadow, turbulence) of obstacles and terrain type are not visible
Sizing	collector area, peak power	swept rotor area, rated power, tower height, tower footprint
Choosing technology	module type, inverter (battery)	great variety of technical concepts (rotor design, type of generator, inverter etc.)
Evaluating operational aspects	no moving parts, repair and maintenance, accessibility (rooftop)	due to moving parts potential safety risks, emission of noise and vibrations, repair and maintenance, accessibility (tower)

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