

## **aeroSmart5 - THE NEW GENERATION OF SMALL WIND ENERGY CONVERTERS (SWEC)**

Soenke Siegfriedsen

aerodyn Energiesysteme GmbH, Provianthausstrasse 9, 24768 Rendsburg, Germany  
Phone: +49 43 31 12 75-0, Fax: +49 43 31 12 75-55, Email: info@aerodyn.de

### **Abstract:**

The last decade has brought with it a rapid expansion in the use of large wind energy converters (WEC) for grid operation. At the same time, however, small systems for decentralized energy production have been neglected. Consequently, there are currently no converter systems available which meet the requirements in terms of robustness, reliability and particularly price in order to become widely successful. The two development firms, aerodyn and SMA, have channelled their entire experience in solar and wind energy technology of the last 20 years into the development of a new small 5 kW WEC. Work was carried out in close co-operation with the Institute for Solar Power Supply (ISET) of the University of Kassel and with funds from the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU). By applying the know-how and many years of experience of all partners involved, a small system was developed within the framework of the three-year overall project. This small system is characterised by a low specific price, a broad area of application, a high level of reliability and a long lifetime.

### **1 Introduction**

Approx. two billion people on earth are not connected to electricity. Most of them live in remote villages with up to a few hundred inhabitants. This "energy poverty" is greatly hindering the development of rural areas in many emergent and developing countries. In these areas, renewable energy technologies could contribute in an important way to the overcoming of energy and environmental problems. These technologies must be integrated into conclusive overall concepts for sustained development, in order to make sure that they can develop their full potential. This is why electricity supply of decentralized consumers represents a global challenge.

Moreover, using small converter systems to directly feed the grid represents an application with great potential. The American Wind Energy Association [1] estimates the potential of small systems to be approx. 4-5 million in the entire United States until the year 2020.

Therefore, the objective of the development project described here is the development of a small-scale wind energy converter system which is highly reliable and inexpensive and at the same time can be optimally integrated into decentralized supply systems and allows for direct grid-connected operation.

### **2 Technical concept**

At the start of the development project, a comprehensive market survey was conducted in order to identify relevant suppliers of small-scale wind energy converter systems and evaluate their products.

Following this preparatory work, a specification book was drawn up which determines all essential system characteristics for global application. Top priority

issues were the minimization of the system's costs as well as its certification according to IEC 61400-2-ED2.0 [2].

The small-scale wind energy converter system named *aeroSmart5* to be made available to the market represents a 5 kW system that went through the same type of development as the mega and multimega watt systems. Integral part of the development were systematic design processes, aero elastic simulations, wind tunnel tests, FEM component studies, FMEA system analysis as well as production optimization. In addition to that, two prototypes were optimized through testing on test stands as well as on the field.

The *aeroSmart5* stands out against other system concepts since it can be easily integrated into both stand-alone AC power systems and the conventional interconnected grid. Decentralized applications are possible due to the parallel operation with the battery power converter "Sunny Island" by SMA, which is designed to control the voltage as well as frequency and rotational speed.

Wind energy in combination with battery systems, small diesel generators or photovoltaic (PV) systems is of great importance for the setup of stand-alone power systems as well as the integration into weak grids, and offers diverse possibilities of electrification.

Another major requirement is that the *aeroSmart5* is resistant against sand and dust. All system components have to be sealed to prevent these particles from getting in. In coastal areas, the negative impact of the salty and damp air has to be taken into account.

The nacelles weight has to be low enough, so that the system can be easily transported and assembled. The *aeroSmart5* can operate with temperatures between  $-25^{\circ}\text{C}$  and  $+50^{\circ}\text{C}$ .

For a successful commercialization of a small-scale system in emergent and developing countries, the system's technology has to be suitable for the local

technical circumstances and at the same time has to provide state of the art WEC technique. Local production of individual components such as the tower should be possible.

### 3 Technical execution

The *aeroSmart5* has been designed as a 3-blade rotor with a diameter of 5.1m and 5 kW rated power. Power is limited via passive stall. Yawing to the wind is achieved through a free yaw downwind rotor. The system uses a 4/6-pole asynchronous generator driven by a single-stage spur gear.

All required components are compactly integrated into a central aluminium casting. They are protected in an efficient way against corrosion and the ingress of external particles. The components were designed to achieve maximum economic efficiency and robustness as well as minimal maintenance. Systematic servicing of the system is required only every five years.

#### Specifications

Rated power:	5.0 kW
Cut in wind speed:	3.5 m/s
Rated wind speed:	13.0 m/s
IEC class:	TC 1
Max. survival wind speed:	70 m/s
Max. annual average wind speed:	10 m/s
Number of blades:	3
Diameter	5.1 m
Rated rotational speed:	133/200 min <sup>-1</sup>
Arrangement to the tower:	down wind
Gear box:	single-stage spur gear
Transmission:	7.68/ 8.76
Generator:	asynchronous generator
Number of phases:	3/1-phase
Frequency:	50 Hz (60 Hz)
Yaw system:	free yaw downwind rotor
Power control:	passive stall
Overspeed control:	flyball governor
1. Braking system:	electromagnetic safety brake
2. Braking system:	centrifugal brake
Hub height	12/18/24 m
Tower:	wired lattice tower, tubular tower
Nacelle mass without rotor:	110 kg
Complete rotor mass:	31 kg
Specific tower head mass:	6.9 kg/m <sup>2</sup>

The main components and functions of the *aeroSmart5* are shown in the block diagram of fig. 3.1. It shows the nacelle with the gear box, generator, brake system, safety chain as well as the system control with all of its individual functions

All components were optimally adapted to each other in order to achieve a light and well priced machine group. In addition to that, all components such as vertical bearing, slipping transducer, gear box, generator, brake system and rotor bedding were combined to a fully integrated machine group. All parts were geometrically arranged in a way that the machine casing became very small and light. It is aluminium cast and weighs only 15 kg.

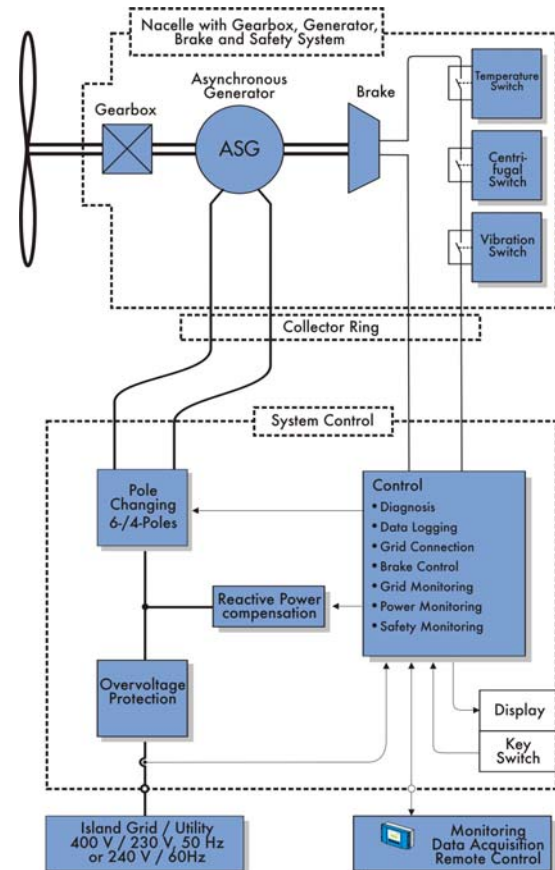


Fig. 3.1 *aeroSmart* block diagram

### 4 Prototype testing

The practical testing and optimization of the components and the whole system was carried out in several stages. At the University of Kassel, several generator variants were extensively measured with regard to efficiency, cos-phi as well as grid connection and temperature behaviour. Afterwards, two complete nacelles together with their control units were examined. The next step was to erect a first prototype on the test field of Windtest Kaiser-Wilhelm-Koog GmbH, bring the system control into operation and undertake an extensive measuring campaign on the system. The second prototype was erected on the Immenhausen test field near Kassel, where it operates as stand-alone AC power system.

#### 4.1 University of Kassel test stand examination

The generator for *aeroSmart5* was designed and optimized at the University of Kassel. Fig. 4.1 shows the efficiency curve traces in relation to the electrical power.

It is obvious that high efficiency values for partial load and maximum load are achieved at voltages below the rated value. Upon 4-pole operation, a maximum efficiency value of approx. 90% for voltages of about 360V is already reached at approx. 2 kW power and then goes slightly down until the rated power is reached.

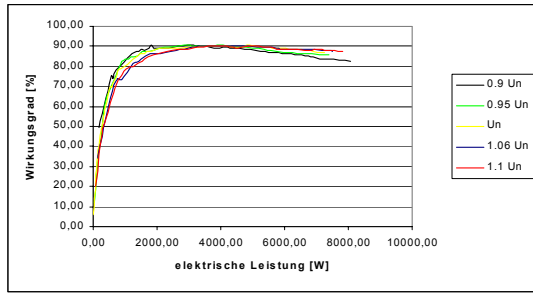


Fig. 4.1: The generator's efficiency curve trace for the 4-pole stage

After these optimizations, similar stator and rotor systems of asynchronous generators were installed into the *aeroSmart5*'s machine casing and examined together with the gear box as entire drive train.

The system was driven by a 200 kW DC motor, and the produced power was fed back into the grid.

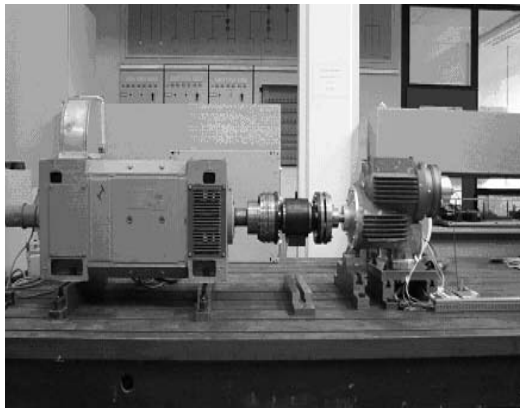


Fig. 4.2: *aeroSmart5* on the test stand

#### 4.2 Field test in the Kaiser-Wilhelm-Koog (KWK)

Following the tests on the University of Kassel's test stand, which turned out to be successful in every respect, the prototype of the *aeroSmart5* was erected on the KWK test field, in spring 2004. The system is mounted on a 12m high lattice tower and connected in parallel to the grid.



Fig. 4.3: Erection on the KWK test field

Fig. 4.3 shows the system upon erection on an existing foundation. It takes approx. 5 minutes for a single person to erect the system.

An extensive measuring campaign was worked out in co-operation with Windtest. The objectives of the metrological examination are on the one hand to check the operational reliability and the safety devices of the system, and on the other hand to examine performance characteristics, yawing behaviour, mechanical stress and thermal characteristics in order to be able to carry out design modifications, if necessary.

Fig. 4.4 shows the measuring system for the *aeroSmart5* on the KWK test field. The anemometry pole serves to measure the wind direction and speed at hub height as well as the air temperature and pressure and the precipitation. The measuring sensors for blade position, generator rotational speed, nacelle position and seven temperature measuring points which are inside the generator, gear box and on the machine casing, are installed on the nacelle. The accelerations in both directions are measured at the tower, directly under the nacelle. Additionally, strain gauge measuring bridges are installed on the four guys.

The characteristic curve of the electrical power at grid feed was at first determined for two different pitch angles.

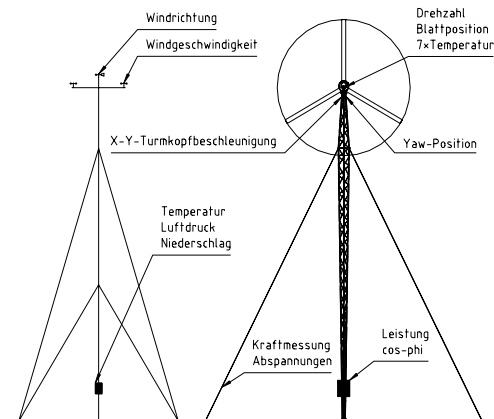


Fig. 4.4: Measuring system *aeroSmart5* on the KWK test field

Fig. 4.5 shows the electrical power in relation to the wind speed as one-minute average value for the upper rotational speed stage. The measurement showed a very good stall behaviour at a pitch angle of 5°. At wind speeds between 13 and 20 m/s, the power curve shows a more or less constant power of approx. 4.5 kW. The stall curve is more flat at a pitch angle of 7°, the maximum power being approx. 6.5 kW.

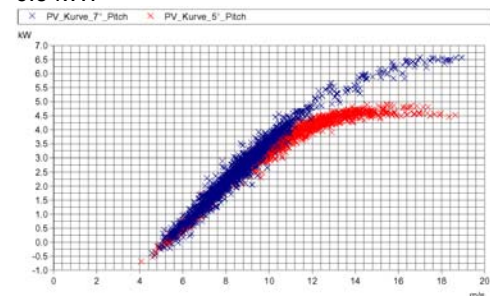


Fig. 4.5: Characteristic power curve

As a result, a pitch angle of 6° was determined for the final product. The system is currently being measured with these blades. The rated power will be 5.5 kW.

Fig. 4.6 shows the system's temperature behaviour with regard to the end windings inside the generator and the surface temperature of the machine casing. At an outside temperature of approx. 15°C and rated power, the generator reaches a maximum temperature of 65°C and a surface temperature at the machine casing of 35°C. This shows that the cooling at the generator and gear box works perfectly, and that even at considerably higher outside temperatures of up to 40°C no problems with the generator coil's insulation and the gear oil are to be expected.

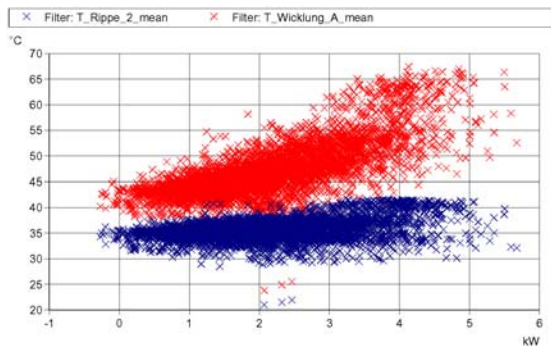


Fig. 4.6: Temperature behaviour *aeroSmart5*

Fig. 4.7 shows the misalignment of the rotor axis to the wind direction in relation to the power. It reveals an average deviation of approx. 5°.

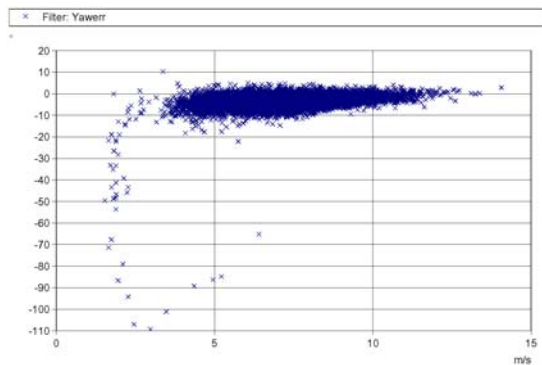


Fig. 4.7 Nacelle misorientation

Fig. 4.8 shows the acceleration at the top of the tower in relation to the power. This graphic representation reveals that an average acceleration of approx. 0.15 m/s or 0.015 g occurs at rated power. The measurements of the individual values with high acceleration are taken at the moments of rotational speed switching. They are sufficiently low, so that the machine is not affected in a negative way.

These first measurements exceeded the expectations for the entire operating behaviour. Fundamental modifications to the system are not necessary.

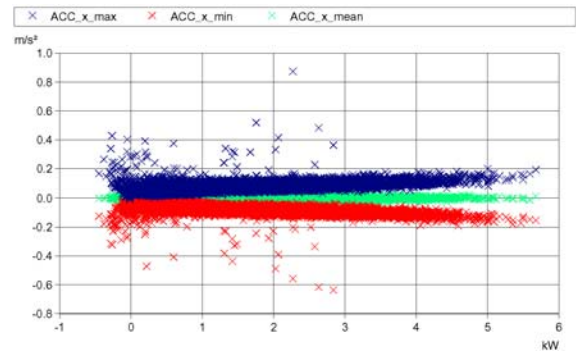


Fig. 4.8: Tower top acceleration

### 4.3 Field test Alte Schanze

The second *aeroSmart5* prototype is being tested under the operational conditions of an autonomous hybrid system. With regard to its electrical integration into the hybrid system, this prototype has to fulfil requirements that exceed those of a connection to the grid. At the "Alte Schanze" site in Immenhausen, approx. 10km north of Kassel, the ISET has set up a test field that allows to measure the *aeroSmart5* at operation, as part of the hybrid system.

## 5 Summary and future outlook

The *aeroSmart5* is the result of three years of development and trial, using the latest development tools. This system fulfils the technical requirements of both stand-alone power systems and direct grid feed. The *aeroSmart5* is characterized by its robust design for a long service life, its low maintenance requirements, gentle dynamic behaviour and low system price. The system's design allows setting the price significantly below the current average market price. The *aeroSmart5* has been optimized for worldwide operation and can significantly contribute to the application of small-scale wind energy converter systems. This offers the chance to help bringing about the breakthrough of small-scale WEC application.

The production of a 0-series and the implementation of the system at important locations throughout the world are planned for spring 2005. Series production is scheduled for the beginning of 2006, after a further trial period of approx. one year. It is planned to develop 2kW and 10kW systems on the basis of the *aeroSmart5* system concept, after the various tests at Windtest KWK GmbH and ISET have been completed and all measurements evaluated. These prototypes can then be put into operation at the end of 2005.

### Bibliographical references

- [1] American Wind Energy Association: The U. S. Small Wind Turbine Industry, ROADMAP – A 20-year industry plan for small wind turbine technology
- [2] IEC 61400-2ED2.0 Wind turbines – Part 2: Design requirements for small wind turbines (draft)