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WIND TURBINES AND ITS APPLICATIONS

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ANNOTATION

The article deals with small wind turbines for non-volatile systems or small smart wind turbine power systems. Not all small turbine manufacturers around the world have access to the engineering capabilities to design an efficient turbine. The purpose of this paper is to provide an easy-to-use integrated method for designing and predicting the performance of wind turbines, as well as demonstrating examples of its application.

The base model for the performance design and prediction method is based on an improved version of the well-established vane element momentum theory coded in MATLAB™. Results: (i) full geometry of aerodynamically shaped and twisted blades that are designed to provide maximum power output for a given wind speed, and (ii) dimensionless turbine performance in terms of power, torque and thrust ratio. depending on the speed ratio of the handpiece. Dimensionless operating characteristics are the basis for dimensional characteristics and synthesis of the rotor to the electric generator with its load.

Two parametric studies illustrate typical results of the design method and performance prediction: change in the calculated tip speed ratio and change in the number of blades. The predicted effect of these parameters on dimensionless performance is in good agreement with common knowledge and experience.

Finally, the interaction of the various turbine rotors and a given transmission/charger is simulated. The selection criteria for the rotor are the annual energy output, the rotational speed of the rotor at the calculated wind speed, as well as in strong winds, and the axial thrust exerted on the rotor by the wind. The complete rotor/transmission/charger assembly has been successfully tested in the wind tunnel of the University of Siegen.

Keywords: small-sized horizontal-axis wind turbine, design, performance calculation, impetus of the blade element.

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INTRODUCTION

Three trends can be observed in the production and supply of electricity: first, the use of free primary, i.e. renewable energy, the avoidance of CO2 emission certificate costs and other end-of-life waste disposal costs. Second, distributed small and unstable energy resources are combined into a small smart grid to improve the reliability and reliability of decentralized networks. "Smart" in this context refers to the control of production and distribution using smart meters, smart appliances, storage media such as batteries and renewable energy. This may be of particular interest to rural distribution networks and the future infrastructure needed for electric vehicles. For example, under the Seventh Framework Programme, the European Commission has supported numerous projects such as “Open Systems for Energy Services”, “Smart… Rural Grid Implementing Sustainable Electricity Distribution Infrastructures, Services and Business Models”, “Scalable Household Management Infrastructure” (FP7 [one]). Thirdly, in some cases, the cost of supplying electricity to the grid (or receiving electricity back from the grid) may exceed all other costs. Connecting to the public network, even in remote areas, may not be economically feasible. This paper focuses exclusively on small horizontal axis wind turbines (HAWTs) for grid-independent or small smart grid systems, fig. 1. It is clear that current and future demand provides sufficient support to support a significant number of producers. In highly industrialized regions of the world, advanced techniques allow high quality products and even mass production, while in other parts of the world, simple manufacturing techniques are needed, Fig. 2. In the past, ill-conceived small wind turbines have damaged the reputation of such machines. Today, standards and testing institutes are increasingly providing consumers with realistic and comparable performance ratings for competing products. Examples are the British Small Wind Turbine Standard [2], the German Small Wind Turbine Annual Market Review [3], and the Austrian Small Turbine Test Site Energie-For Schungspark Lichtenegg [4]. On the other hand, not all small turbine manufacturers, especially small-scale manufacturers, may have access to engineering capabilities to design an efficient turbine. There have been a number of studies on wind turbines focusing on structural analysis, rotor dynamics and shape optimization of wind turbines. Yuan Chang Chen et al. [19,20] and Wel Chen et al. [21], have recently studied and reported in detail on blade rotor dynamics and blade modeling. Many computational approaches have also found application in the aerodynamic design of wind turbines, such as computational fluid

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dynamics (CFD), wake method, and blade momentum theory (BEM). The BEM theory is widely used in the aerodynamic design of wind turbines due to its simplicity and accuracy [26]. With blade optimization, a power factor close to the Betz limit of 59.2% can be realized with wind turbines.

Most wind turbine optimizations are carried out for wind turbines operating under design conditions. Wind turbines are subjected to various operating conditions. In addition, matching the electrical generator to the performance curves of the turbine is fundamental to ensure that the components are protected from extreme structural stresses.

Figure 1. Examples of micro and small wind turbines in the Netherlands

Structure and Performance Calculation Procedure

The turbine design methodology includes three main steps: (i) designing the HAVT rotor, especially its shaped and twisted blades, (ii) predicting its performance in terms of shaft power, shaft torque and axial thrust on the complete rotor, (iii) the total power generated by the "load" torque from the generator. After these last steps, it is easy to determine the total power generation for a given—say, annual—wind speed histogram. Ultimately, measures must be developed to achieve low wind speed on turn on and off function in high winds. The last steps are beyond the scope of this article.

The purpose of this exemplary case study is to develop a HAWT for a small generator/charger. The analysis involves comparing the performance curves of the wind turbine rotor with the torque characteristic of the charger. After fabrication, a final wind tunnel experiment confirms the theoretical analysis.

For experiments, the rotor was installed in front of the transmission, consisting of a steel shaft, separate bearings and an electric generator. The charger was

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connected to the generator. The entire assembly has been tested in the wind tunnel of the University of Siegen. This wind tunnel is of a closed type, providing a maximum wind speed in the wind tunnel of 70 m/s with a turbulence intensity of less than 0.35%. On fig. 12 shows an experimental setup in a wind tunnel (all dimensions are in millimeters). The wind speed was measured with a propeller anemometer, and the rotation speed was measured with an optical laser tachometer. The wind speed changed in steps. During steady operation, the speed of rotation of the turbine was recorded. It is important to note that the air density in the wind tunnel laboratory was approx. ρ= 1.17 kg/m3, which leads to different turbine dimensional characteristics compared to the previous sections. This has been taken into account. Ideally, the power at the rotor shaft should be measured. It was impossible. Instead, electrical power was measured.

A comparison of the rotational speed of the entire rotor/charger assembly in volumetric mode ("Battery discharged - charge") at various wind speeds is shown in Figure 13 on the left. Obviously, the “loading” of the rotor by the electric generator is very close to what was expected from the previous analysis. This partially confirms the aerodynamic design of the rotor. The difference between the predicted power on the rotor shaft and the measured electrical power, fig. 13 on the right is a measure of the overall electrical efficiency of the entire assembly. The big loss is connected with the electric generator. Its electrical efficiency characteristic has been measured separately - similar to the full generator/charger/battery characteristics previously, and is depicted for n = 560 rpm in fig. 14. At PS = 29 W (corresponding to c0 = 6 m/s), the electric power of the generator is 47% efficient. Other electrical losses are associated with the battery charger and - from c0 = 7.5 m/s - with a resistive load resistor to protect the battery. Ultimately, fundamental errors due to blockage of the wind tunnel test section by the rotor and potential reduction in turbine efficiency due to manual fabrication may explain the rotor's lower-than-predicted power factor. Note that the turbine shaft power could not be measured directly during the wind tunnel campaign.

Summary and Conclusion

An analytical method for the aerodynamic design of horizontal axis wind turbines is described, including performance prediction. The theory behind design, shaft power, and thrust prediction is an advanced version of the well-established blade-element-momentum (BEM) theory, coded in our proprietary MATLAB™

deapWind program. The procedure yields a geometry of aerodynamically shaped and twisted blades that are designed to produce maximum power output for a given design wind speed. Two parametric studies demonstrated typical results of the design method and performance prediction: (i) a design option for tipping speed ratio λ; the higher λthe design, the higher the rotational speed at a given wind speed and the lower the torque. Therefore, the choice λof design allows the turbine to be adapted to locations with low or high average wind speeds. In addition, the higher λthe design, the thinner the blades, which can affect the quality of workmanship and the reliability of the design. (ii) Changing the number of blades B in the rotor with λthe design unchanged; as expected, the results showed that the dimensionless performance of the turbine is almost independent of the number of selected blades; the negligible influence of B is due to the influence of Re and various aerodynamic loss mechanisms taken into account in the improved theory of momentum of the blade element. Thus, the selection criterion for B is, among other things, the technical feasibility of many thin or a few more massive blades, and not the power output, as is sometimes naively assumed.

After all, the more detailed case study was for a micro wind turbine for a small, inexpensive generator/charger. The aim was to provide turbine blades with high aerodynamic quality, which could be produced using technologies available in less developed regions of the world. The analysis included comparing the performance curves of the turbine rotor with the torque curve of the charger, fabrication of the rotor, and a final wind tunnel experiment to validate the theoretical analysis. The starting point was a yearly histogram of measured wind speed data collected at a candidate site in central rural Kenya. Prior to wind turbine design, the torque/speed characteristic of a generator was determined experimentally in the laboratory by connecting the generator shaft to an auxiliary motor. Torque was measured at any set speed using a counter torque measuring shaft. The generator was connected to a charge controller and a dead battery.

The interaction of various turbine rotors and transmission/battery charging has been simulated. The criteria for selecting the rotor were the annual output of energy on the shaft, the speed of rotation of the rotor at the most prevailing wind speed and in strong winds, as well as the axial thrust acting on the rotor by the wind. A blade manufacturing technology was chosen that required only a standard carpentry shop. Compared to 3D printing and additive manufacturing, this technology is simple, cheap, and available to less developed countries to develop wind turbines to power communities outside of national grids. Finally, the complete rotor/transmission/charger assembly was tested in the wind tunnel at the University of Siegen. The rotation rate for various wind speeds is very close to what was expected from the previous analysis. This partially confirms the aerodynamic design of the rotor. The difference between the predicted power on the rotor shaft and the measured power of the electric generator. i.e., the overall electrical efficiency value is mainly related to the electrical losses in the alternator and battery charger circuit. Future efforts should include passive yaw and storm protection. The tail vane can act as a passive yaw system or a downwind rotor setting. Predictive thrust can facilitate the design of any mechanical tilt mechanism and ultimately the sizing of the tower. Advanced electrical control can help to safely shut down in high winds and start the turbine early.

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