Self-build small wind turbines

A review

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Abstract

Self-build small wind turbines are used for rural electrification in the developed and developing world as well as for educational purposes. To give an overview about self-build small wind turbines a systematic literature review was conducted. The identified literature deals with two different vertical and horizontal axis turbine designs. The vertical axis turbines are both prototypes while one of the horizontal axis designs, the design by Piggott is widely used in rural electrification projects. Different papers dealing with the optimization of the Piggott design exist. In retrospect the conduction of a holistic review was not possible due to limited resources and length of this review. Nevertheless it can give a quick overview and a starting point for further research.

Keywords: small wind turbines, self-build, horizontal axis, vertical axis,

1 Introduction

Small wind turbines (SWT) are often used for off-grid electrification in rural areas of developing countries but also in isolated regions in the developed world [1]. Beside commercial turbines manuals for self-build turbines are available. These manuals are used in electrification projects of different associations as engineers without borders or even for educational purposes (e.g. the project windmobil in Luxemburg). This review paper summarizes published technical reports and manufacturing manuals in connection with small self-build wind turbines found by a systematic literature review. The aim of this paper is to give an overview about the variety of different types of self-made wind turbines and their documented optimizations. As an initial point this paper can help non-profit organizations as well as individual persons or education institutions to identify relevant literature.

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2 Methods

To collect the data, a systematic literature search according to the snowballing approach described by Wohlin [2] was conducted. Relevant literature was identified using the search engine of the authors host university called "FINDEX". Included studies have to be a manual or illustrate the results of an modification on a small wind turbine or a component of it. Some relevant literature was published in Spanish and is therefore not included in this review. To begin the snowballing process the search string *("locally manufactured" OR "self build" OR "self made") AND "small wind turbines"* was used. The starting set included 13 papers.

Afterwards the identified literature is classified by axis of rotation, summarized and evaluated shortly.

3 Results

The ten papers identified by the systematic literature review are shown in Table 1. Afterwards the papers are shortly presented in subsections in respect to the axis of rotation. Literature in respect to horizontal axis of rotation mainly focuses on the manual of Hugh Piggott. Even it is not published in an academic outlet this manual is additionally included.

Tab. 1: Publications dealing with self-build small wind turbines identified by systematic literature review

Axis of rotation	SWT model	Ref
3***Vertical**	Al-Bahadly	[3]
	Venetica M1	[4]
	Venitica M1	[5]
8***Horizontal**	Piggott manual	[6]
	Piggott rotor	[7]
	Piggott rotor	[8]
	Piggott rotor	[9]
	Piggott generator	[10]
	Piggott generator	[11]
	homebrew	[12]

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3.1 Vertical axis small wind turbines

The publications in connection with vertical axis turbines deal with two different designs. Al-bahadly presented a turbine based on the Savonius rotor driven by drag forces. The design published by Bassett is based on an hybrid design which is driven by lift and drag forces. A more detailed construction manual of this design called Venecia M1 is online available [13].

Design Al-Bahadly [3]
The rotor is made out of two cut in half and stacked 44 gal drums. The rotor is 1.5 m tall with a diameter of 0.65 m. To reach the needed generator speed a transmission from rotational axis to generator is needed. The support frame is constructed out of galvanized steel. The calculated power output is 27 Watts and 0.65 kWh per day at a average wind speed of 10 m/s. The author estimated construction costs of $NZ 500.

Design Bassett (Venetica M1)[4]
The rotor consists of three blades out of a pine profile wrapped in sail cloth material. It is 1.524 m tall with a diameter of 0.927 m (fig. 2). The generator connected directly to the rotational axis is based on a design by Hugh Piggott. A transmission is not needed. The calculated power output is 100 Watts at 10 m/s. The results of trials show an output of 45 Watts at 10 m/s wind speed [13]. Additionally the author proofed the possibility of blade production with 3D-printing for this turbine in another research paper [5].

3.2 Horizontal axis small wind turbines

Literature focuses mostly on the design of Hugh Piggott [6]. Only one of the evaluated papers [12] focuses on another design called homebrew design [14]. This manual was not available in the library of the authors home university. Due to the missing basic literature the paper of Louie [12] is excluded in this study.

The manual published by Piggott is often used in rural electrification projects [1]. The evaluated papers mainly focus on the optimization of rotor or generator of the turbine. The general design is presented in fig. 3. Therefore this chapter is subdivided according to this focuses.

Rotor
The original manual by Piggott describes different rotor diameters from 1.2 m (rated power 200 Watts) to 4.2 m (rated power 1000 Watts) and tip speed ratios between 5 and 7. The blade with a complex twisted airfoil is carved out of wood. Hosmann [7] constructed a turbine with 1.8 m rotor diameter according to the manual, analysed its characteristics, implemented a new untwisted airfoil (NACA4412) and repeated the tests. The new blades led to a 11 % higher rotor efficiency but higher noise production at low wind speeds of 4 m/s. At higher wind speeds the efficiency improvement decreases from 5.2 % at 5 m/s to 1.2 % at about 8 m/s. Melendez-Vega et al. [9] replaced the original Piggott 1.2 m blades with ones made out of PVC pipes. This configuration slightly lowered the performance at wind speed under 6 m/s but increased it at higher wind speed. At 10 m/s the modified turbine had a 30 % higher performance. Latoufis et al. [8] examined the influence of eroded edges of an 2.4 m turbine after 18 months of use. The noise produced by the turbine increased significantly at all wind speeds while the output power was stable under 8 m/s wind speed and decreased at rated wind speed of 11 m/s about 23,7 %.

Generator
The original manual presents different coreless generator configurations for each rotor size described earlier and system voltages of 12 V, 24 V and 48 V. Sumanik-Leary et al. [10] changed the neodymium magnets (class N40) of the 48 V generator connected to 2.4 m turbine to ferrite magnets (class F8) which have a lower magnetic field strength but are cheaper and less sensitive to corrosion. Generally at higher rotational speeds from around 240 rpm the neodymium magnets had an approximately 5 % higher overall efficiency in the laboratory tests. Field test were only realized with the neodymium generator so no comparable data of a ferrite generator was generated. For probably the same generator size with neodymium magnets Shea and Ludois [11] added ferrous fillings into the stator windings. This led to a 50 % lower magnet thickness maintaining the electrical power output.

4 Conclusions

4.1 Vertical axis

Al-Bahadly [3] evaluation
The paper presents the planning of the turbine step by step and indicates the general theoretical background. Although the generator properties are not shown as well as the devided costs by parts. Therefore it is not transparent how the author considered the construction costs of NZ$ 500. Even if the designed prototype is build, no actual testing was done to confirm the theoretically calculated power output.

Venetica M1 [4, 13] evaluation
The paper presents the planning and manufacturing step by step more generic than Al-Bahadly and does not present the theoretical background. Also the estimation of the turbine power coefficient of 0,3 is quiet optimistic. The measured power output of less than 50 % of the estimation documented at the website underlines this, also if there are other influences on the output like the electrical system. Another question, also mentioned by the author, which has to be answered is how the cloth behaves in the rain.

Generally the vertical axis wind turbines are more suitable than horizontal axis wind turbines for turbulent airflows. Due to their prototype status and low power output both described turbines are currently not recommandable for electrification projects.

4.2 Horizontal axis

Rotor

The original manual is a hands on guide and enables people to build a small wind turbine with little technical knowledge. On the one hand the blades Hosmann [7] recommends improve the rotor efficiency and simplifiy the blade production. On the other hand the airfoil is thinner so the strength of the blades has to be evaluated. The PVC blades Melendez-Vega et al. [9] introduced are relatively easy to produce and have a significantly higher power output at wind speeds over 6 m/s but also have to be evaluated in respect to their strength. The paper by Latoufis [8] shows a big impact of the blade condition on the performance. They doesn't describe which wood they used or which could be a better alternative.

Generator

Due to the absence of field test data, Sumanik-Leary et al. [10] couldn't verify the laboratory results. The reduction of magnets Shea and Ludois [11] propose is associated with a cogging torque of 4 to 7 Nm while a similar generator which was tested by Hosmann [7] had a cogging torque of 0,05 Nm. The paper hasn't examined whether this increase would lead to start up problems or not.

To sum up the airfoil alternative described by Hos could be a good alternative for regions with low wind speed and where noise does not play a mayor role and building a bigger turbine is not possible. The design presented by Melendez-Vega et al. can be useful in regions with higher average wind speeds and where the availability of PVC pipes is not critical. Sumanik-Leary et al. [10] showed that the originally used neodymium are more efficient as the less corrosion sensitive ferrite ones. If it is useful to replace them even so, the difference in lifetime has to be evaluated. The use of iron fillings in the stator windings Shea and Ludois [11] proposed to reduce the mass of magnet increase the the cogging torque extensively to 4 Nm to 7 Nm which can be critical to the start up behavior of the turbine.

5 Outlook

In the evaluated set of papers, studies dealing with technical aspects as defined earlier in connection with self build small wind turbines are not really widely represented. For further research the search string should be extended or varied with typical and specific searching keys e.g. "VAWT" or "HAWT" which were not possible to include in this due to limited resources. Furthermore online forums where ideas are shared and discussed should be taken into account. To name only some there is the solar-electric forum with a wind power category [15] or one in Germany called "Kleinwindanlagen" [16].

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