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Development of guidelines for the construction of wind turbines using scrap material

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Abstract

Worldwide, approximately 2 billion people lack access to reliable electricity. This results in limited access to refrigerated foods and medicines, emergency hospital facilities, and lighting. A lack of lighting alone is known to prevent education of children, especially girls. Providing reliable access to electricity is essential in raising the quality of life for 2 billion people. However, electricity generation is usually expensive, or has high capital costs and requires a high degree of technical knowledge. To help address this issue, a set of guidelines for the development and manufacture of different wind power generation systems has been written. The guidelines are designed such that the users can build wind turbines based on the scrap material that they have available. To ensure the guidelines were suitable, four proof-of-concept devices were made and tested in the field and in a wind tunnel. The results show that power generation is possible with limited equipment and technical capability. However, further work is required to optimise the manufacturing processes.

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1. Introduction

One fifth of the global population does not have access to electricity. Furthermore, around 84% of this figure represents people living in rural areas [1]. Lack of access to reliable electricity can have significant effects on education, economics, health, and gender equality [2, 3]. There is a need for greater access to electricity worldwide, but financial limitations are a significant impediment. Therefore, it is required to provide reliable access to electricity as inexpensively as possible.

Power generation can be either centralized or decentralized. Centralized systems require high initial investments for power plants and distribution infrastructures, but their larger capacity provides more users with access to electricity. Decentralized systems require smaller initial investments due to their residential or community-sized infrastructures, but provide fewer users with access to electricity. In order to provide reliable electricity to those who do not have access to it, consideration must be given to their limited financial capabilities and to the remoteness of the rural areas where most of them live. Greater focus should therefore be placed on small-scale decentralized power systems. Additionally, in order to promote sustainable power generation, the particular focus of the current work is on small-scale renewable power sources.

There are several types of renewable power systems, but most are not suitable to all users. Hydropower, tidal and wave power systems can provide pseudo-constant and somewhat predictable power generation, but are restricted to regions with sufficient flowing water [4]. Similarly, geothermal power systems provide predictable and controllable power generation, but require large infrastructures to be built and are restricted to regions with sufficient subterranean thermal energy [5]. Solar photovoltaic cells are often expensive [6], while solar thermal systems are not suitable for small-scale energy generation [7]. Wind turbines are

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dependent on sufficient wind speed, but are a proven technology and less expensive than several other power generation systems. Therefore, the implementation of small-scale wind turbines is deemed the most adequate solution to provide electricity to many off-the-grid rural communities.

Commercial small-scale wind turbines are typically unaffordable to those living in impoverished rural communities. However, making use of existing and potential scrap material to manufacture small-scale wind turbines enables users to benefit from renewable power without having to depend on external support. Scrap material is widely available in most parts of the world, and local ingenuity can be used to transform it into wind turbines that are better suited to local conditions. Unless certain skills or materials are required to service the power generation equipment, the construction and maintenance of these systems should be inexpensive, and thus feasible for impoverished rural communities. It is therefore optimal to enable communities in resource-constrained regions to build their own wind turbines that are fit for purpose.

The aim of the detailed project was to create a set of guidelines for the construction of wind turbines using scrap material. This includes assessing the proof-of-concept by manufacturing and testing four different wind turbine designs.

2. Background

Wind turbines are classified as either horizontal axis wind turbines (HAWTs) or vertical axis wind turbines (VAWTs) [8]. These designs have different advantages and disadvantages, thus preventing a universal wind power generation solution. Horizontal axis wind turbines have higher theoretical efficiencies than their vertical counterparts, but their performance is sensitive to wind direction [8]. Yaw control can mitigate this issue, but it also increases design complexity. Furthermore, HAWTs are often subject to a minimum cut-in velocity, and require good structural rigidity to support several components above ground level [8]. Vertical axis wind turbines can be less complex to design and manufacture than their horizontal counterparts. Additionally, they often do not have a minimum cut-in velocity, and are designed such that their gearing systems and generators are located at group level [8]. However, due to being less efficient, VAWTs generate much less power than equivalent sized HAWTs [8]. Based on these differences, the guidelines consider and detail both designs.

The mechanical components with the greatest influence over the performance of a HAWT are the blades. Good blade design should consider the lift and drag generated, structural rigidity, vortex shedding, and tangential velocity, among other factors [8, 9]. Several features can be added to the blades in order to improve their efficiency, torque, and rotational speed characteristics. These include the use of airfoils and cambered cross-sections, taper, and twist [9, 10]. Proper selection of the number of blades used and their radius can also improve the performance characteristics of a HAWT [9, 10].

Vertical axis wind turbines can be classified as being based on lift or drag. The Darrieus and H type wind turbines are the most common lift based designs, while the Savonius wind turbine is the most common drag-based design [11]. Despite having smaller efficiencies [12], Savonius wind turbines are simple to manufacture and suitable for different environmental conditions [13]. It could be argued that the larger efficiencies of the Darrieus and H-type wind turbines validate their difficult manufacture, but HAWTs are still able to achieve greater efficiencies and are easier to build [14, 15]. For these reasons, Savonius wind turbines were the only VAWTs detailed in the guidelines.

Rotor design has significant influence on power production from Savonius wind turbines. Similarly to HAWTs, consideration should be given to lift and drag generation, structural rigidity, vortex shedding, and tangential velocity, but differently. The performance characteristics of Savonius wind turbines can be improved with proper selection of blade radius and shape [16], number of blades used and their positioning [17], and aspect ratio [18, 19, 20]. They can also be improved with the addition of endplates [12] and multiple vertical stacks [17].

Generators are components common to HAWTs and VAWTs that convert mechanical power into electricity. Ideally, the generator should have low start-up torque and high efficiency in order to maximise the performance of a wind turbine. It should also be able to produce a suitable voltage output at a low rotational speed. The most adequate generators for DIY small-scale wind turbines are the direct current, permanent magnet synchronous, and wound-field synchronous configurations [21]. Alternatively, their motor counterparts can also be used.

The guidelines present different alternatives for the construction of HAWTs and Savonius wind turbines, in addition to information on how to source and use generators. Recommendations are given on how to improve the performance of a particular wind turbine design, while keeping in mind the material and manufacturing constraints present in developing nations. Effectively, the guidelines are an interactive manual that encourages the user to choose their own wind turbine designs based on what capabilities and materials are available to them.

3. Methodology

Assessment of the wind turbine prototypes was conducted by first testing the generators in isolation from the blades, and then testing them in conjunction with them. The generators were tested by connecting their shafts to a metal lathe capable of controlled torque and rotational speed. The metal lathe allowed for rotational speeds between 60 RPM and 2000 RPM, but the testing speed range varied for each generator based on their recorded outputs and vibrational movement during testing. In order to determine the start-up torque, an Extech 475044 force gauge, which has a 20 kg range and 0.5% accuracy, was used. In order to test the power and voltage output, a Digitech QM1523 multimeter, which has a 1.2% AC voltage accuracy and a 0.8% DC