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The Design and Production of a Portable Small Wind Turbines

Philip Nelson Mosely

Dulwich College, London, SE21 8DJ, England
philipmosely12345@gmail.com

Abstract: *Electricity is an indispensable energy source in today's world, and it is related to almost every aspect of human life. However, there are still many occasions when a stable electricity supply is not available, especially in outdoor activities. It is therefore of great significance to design a portable power generation device that can utilise natural energy sources. This paper presents the design of a foldable wind turbine that can be readily folded and unfolded without the use of tools. The device is designed to efficiently utilise wind energy for the purpose of charging power banks. This paper will present the design and several iterations of this first-generation small-scale wind turbine. Subsequently, an evaluation of the small-scale wind turbine will be conducted, and recommendations for potential improvements will be provided.*

Keywords: *Portable power generation device, Foldable wind turbine, Small-scale wind turbine*

1. Introduction

There has been a global increase in camping, with the percentage of campers camping for the first time rising from 4% to 21% between 2019 and 2020[1]. In 2020, the United States had 86 million households engaged in camping activities. Many of these households may desire to remain connected to the digital world via electronic devices while off-grid. The utilisation of electronic devices necessitates the provision of electricity, which must be transported to the site via batteries or the deployment of substantial generators that operate on heavy combustible fuels such as gasoline[2]. Given that the average price of gasoline in the United States on August 14, 2024, was 3.484 dollars per gallon, it is evident that this fuel source is not only costly but also subject to limitations in terms of the quantity that can be transported on an expedition. This presents a significant challenge in ensuring a reliable and consistent electricity supply to campers, mountaineers, conservationists, and the numerous individuals who are required to spend extended periods, often days or weeks, in off-grid locations. One potential solution is the sustainable harvesting of energy from the environment, which has the additional benefit of not emitting greenhouse gases. This issue has been addressed through the use of solar panels. Commercial portable solar panels, such as the 40-watt X Dragon, offer numerous advantages. They are lightweight, weighing only 2.2 pounds. This is appropriate for individuals residing in regions with abundant sunlight. However, there are many locations that are subjected to overcast conditions, necessitating the availability of alternative renewable energy sources. The solution presented in this paper is a portable wind turbine designed to charge electronic devices with a power consumption of no greater than 100 Watts. Furthermore, this paper will provide a detailed account of the design, construction, testing and discussion of the aforementioned subject matter.

A wind turbine is a device that harvests energy from moving air. The majority of existing literature has concentrated on large-scale conventional wind turbines, which are capable of providing several megawatts of power[3]. The present paper focuses on a small-scale wind turbine with a blade span of no more than 0.5 metres in diameter. The design of the portable wind turbine is informed by the availability of power banks. A power bank is a portable device that stores electricity, typically comprising multiple rechargeable cells with a combined capacity of approximately 10,000 milliampere-hours (mAh)[4]. The portable wind turbine serves to reduce the load of eight or more power banks to that of five, or alternatively, it can act as a consistent source of power. This necessitates that the device be lightweight (less than 1.5 kilograms), highly portable, and therefore very compact, as well as robust and waterproof, so that it can withstand the elements in the most extreme conditions. This paper will present the findings of the research and development undertaken on this inaugural portable wind generator. Subsequently, a comprehensive overview of the design will be provided[5]. The methodology employed for testing and the findings of the analysis will also be presented.

The utilisation of wind as a source of energy has been a practice of humanity for millennia. The earliest known examples of sails used for propulsion date back to 3100 BC in the Mediterranean region. The use of windmills for the milling of grain and the sawing of lumber can be traced back to the time of King Hammurabi of Babylon, who reigned in 1700 BC. Wind pumps have been used for the provision of water for irrigation since that time[6]. The concept of harnessing wind energy is not a novel one. In the modern era, wind turbines account for 10.2% of the United States' energy supply. However, there is a paucity of attention directed towards small-scale wind turbines. Small-scale wind turbines typically have a rotor diameter between 10 cm and 100 cm. Wind turbines can be classified into two main categories: vertical and horizontal. Vertical axis wind turbines (VAWTs) are configured to rotate perpendicular to the ground. In contrast, horizontal axis wind turbines (HAWTs) are designed to spin in a direction parallel to the ground. VAWTs can be classified into three main modern designs: the Savonius VAWT (a), the curved-blade Darrieus VAWT (b), and the straight-blade VAWT (c), as illustrated in Figure 1.

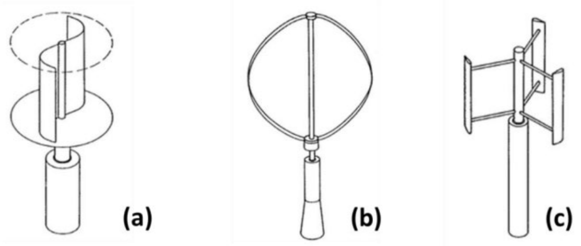

Figure 1: Savonius VAWT, Curved Blade Darrieus VAWT, Straight blade VAWT.

The preference for HAWTs is based on their typically 10% higher efficiency than VAWTs. In their study, Simatupang and Sulistiohadi selected an HAWT design as the optimal choice for a portable wind turbine. Subsequently, HAWTs must undergo optimisation with respect to different geometric parameters, necessitating the adjustment of blade angles, twist angles and blade numbers. Given the dearth of research on small-scale wind turbines, there are only a few examples of optimised blade profiles. Vardour et al. compare the rotation rates of various wind turbine rotor models. The models in question are the NACA 0012, NACA 4412, NACA 4414 and NACA 23102. The NACA 4415 profiles with a 0-degree twisting angle, an 18-degree blade angle and four blades were identified as the most efficient. Given the dearth of available data on optimal blade profiles, it is necessary to conduct simulations using computational fluid dynamics software and other simulators in order to identify the most promising blades. This paper does not address the topic of simulations, due to the limited accessibility of such techniques and the requisite technical expertise. Nevertheless, further research should employ this valuable tool to rapidly prototype and design blades[9].

It is crucial to differentiate between lift and drag in the context of wind turbines. Both forces are provided by the wind, but different blade profiles are required to exploit them. When a plane is exposed to an incident wind, it encounters a surface force. This is an aerodynamic force. If the force is parallel to the wind flow, it is called drag. If the force is perpendicular to the wind direction, it is called lift. The magnitude of these forces can be seen in Figure 2. Small wind turbines typically take advantage of drag due to their poor aerodynamic performance. Furthermore, these drag forces can be calculated, as Kishore provides a detailed account of this in reference [8]

$$.D = C_D \frac{\rho}{2} a u_\infty^2 \tag{1}$$

$$L = C_L \frac{\rho}{2} a u_\infty^2 \tag{2}$$

There are several commercial SSWTs of which are relatively accessible. However, they are very few truly portable SSWTs. The most portable commercial SSWT this paper could find is the Shine turbine, developed by Aurea technologies. It is extremely compact having a maximum diameter of 10 cm with a length of 35 cm, it has an extended rotor diameter of 60 cm and weighs a total of 3 pounds. This turbine powers a 40 watt generator with a 12000 mAh internal battery [10]. The business has proven a clear interest in turbines such as these reaching their $15000-dollar fundraising goal in an hour.

2. System Overview

A variety of calculations can be performed by determining the theoretical power output and specifications of a turbine. I thus elected to impose constraints on my design, with the overarching objective of ensuring portability. This necessitated a maximum length for the turbine and blades of 30 cm. The device must weigh no more than 1.5 kilograms and the diameter of the rotor may not exceed 15 centimetres. Furthermore, the manufacturing techniques and the acquisition of certain components proved to be significant impediments to achieving optimal efficiency, which must be addressed in future iterations.

The portable wind turbine is comprised of eight principal components: the blades, folding hub, generator, electronics, housing and body, battery, yaw system and the mounting system. It was therefore essential that all of these components operate at maximum efficiency, given the low power rating of the device. Any loss of energy could have a severe impact on performance.

This paper proposes the use of a three-phase brushless motor. The decision to utilise a three-phase brushless motor was based on its numerous advantages. These include a low starting torque, an extended lifespan due to the absence of brushes, and a higher efficiency compared to single-phase motors. The use of a three-phase motor as the generator was selected due to its ability to produce three sine waves, in comparison to a conventional single-phase motor, which only produces one. This configuration is more efficient as it facilitates a more constant flow of power. Two commercially available generators were identified with power ratings below 100 W: a 20 W and a 60 W motor. The 20 W generator, as illustrated in Figure 2, was insufficient for the SSWT requirements, producing a maximum of 4 volts even when scaled up with the MMPT charge controller. In contrast, the 60 W motor was capable of generating the requisite wattage to power the battery when operated at 600 rpm[11]. This was validated using a stepper motor to drive the generator and a voltmeter to record the output, as depicted in Figure 3.

Figure 2: 20-watt generator.

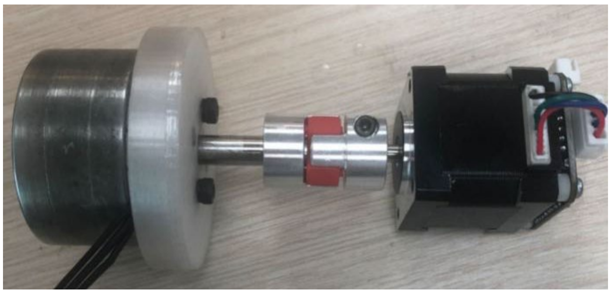

Figure 3: 60-watt generator with a stepper motor connected to a program on the computer that can very its rotation.

2.1. Electronics

The electronics consisted of two components a Module control incarare solara MPPT charge controller and a rectifier bridge formed from 6 diodes wired to a PCB board, as is shown in Figure 4. This led to a Type-C power output which would be connected to a power bank.

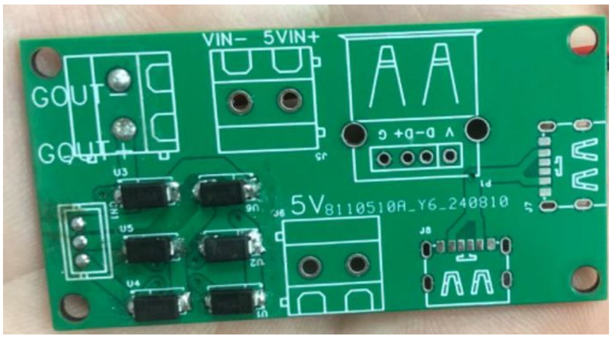

Figure 4: Rectifier bridge from 6 diodes.

2.2. Power bank

This paper decided upon a power bank as they could be easy to source as well as their ability to be swapped out allowing for one battery bank to be charging in the wind turbine and a second one to be within the tent charging your devices. A cumtech 10000 mAh battery was employed.

2.3. Blade

2.3.1. Design of the first blade

The approach taken in this paper was largely influenced by the design of traditional wind turbine blades. This was due to the lack of information available regarding the optimal blade design for small-scale wind turbines. The blade was modelled in SolidWorks to conform to the conventional design of a wind turbine blade, with the exception of the incorporation of shark fins, which are a common feature of larger wind turbines and serve to reduce noise pollution[7]. This was an unnecessary precaution, given the diminutive size of the wind turbine and the consequent minimal impact on noise pollution. The 3D-printed model was constructed in three sections, with a total length of 50 cm, as illustrated in Figure 5. Subsequently, the blade was hand-sanded in order to reduce drag. The generator was then tested with four of these blades. However, the blade design was ultimately deemed ineffective due to the fact that conventional wind turbines have an 80-metre diameter blade span and are, on average, 80 metres high. The blades are designed to generate lift, which is not significant enough at low wind speeds of under 7 metres per second. [8].

Figure 5: First blade design.

2.3.2. Design of the second blade

The second blade modification entailed an increase in the twist angle and a concomitant increase in the blade angle, thereby providing for greater lift and a more curved blade. The printing of these blades resulted in consistent failure due to the blades' considerable height, which caused them to vibrate. A resin printer was employed as it is not susceptible to vibrations and generally exhibits superior print quality. The item was produced in two sections at a facility specialising in the use of three-dimensional printers. The absence of quality control at the manufacturing facility resulted in the shipment of unpolymerised components. This resulted in the joint being reinforced with tape, which may have had an impact on its functionality. The blade in question measured 50 cm in length and was configured with four blades, as illustrated in Figure 6. The testing of blade iterations was hindered by the lack of wind, which was a consequence of the environmental and geographical constraints present. This issue was addressed by the use of fans, although this solution did not encompass the entirety of the blade span, thereby undermining the reliability of the resulting data. The blades remained incapable of autonomous rotation. However, once initiated, they were observed to continue spinning at a maximum of 50 rpm, as recorded by an rpm monitor. A rotary motion was observed when a stepper motor was connected to the generator, indicating that approximately 600 rpm was required to produce 1 watt. The use of a fan blade from a typical desktop fan attached to the generator resulted in a higher rpm, reaching 1300 rpm. However, this was insufficient to provide effective lift over a small area. Consequently, the design of blades closer to those of fans and propellers, which utilise the resistive force of the wind, may prove more effective.

Figure 6: Second blade iteration resin printed.

2.3.3. Third blade design

In order to optimise the blade's drag coefficient, the thickness was minimised in accordance with the recommendations of Clausen et al. [10]. This presented a significant manufacturing challenge, as a 3D printer requires a minimum thickness for successful printing. This resulted in a compromise, as the subsequent iteration sought to combine drag and lift by incorporating an aero foil that could still generate lift. The blade configuration was modified by increasing the number of blades from four to six. This was done because the number of blades is typically constrained by considerations of structural integrity and weight. As these blades were small, they did not present a threat to structural integrity. By making the body extremely light, it was possible to accommodate the additional weight of the blades. This resulted in a configuration of six blades, each 25 cm in length, with a similar twist angle and blade angle to those of previous iterations, as illustrated in Figure 7.

Figure 7: Third blade iteration.

2.3.4. The folding hub

The folding hub enables the blades to be folded into the body. This is achieved through the utilisation of a primary bolt that serves as an axle and a spring pin that enables the blade to be folded in and out by exerting downward pressure on the pin. This configuration enables the blade to be engaged in either a 0 or a 90 degree position, as illustrated in Figures 8 and 9. The hub is 3D printed; however, in subsequent iterations, the hub will be made thinner to reduce length and its width will be decreased. This will be achieved by modifying the design of the hub and that of the blade. Additionally, new iterations will be designed using carbon fibre.

Figure 8: Folding hub most recent iteration with blades deployed.

Figure 9: Folding hub with blades in closed position.

2.4. Mounting system

2.4.1. Trekking pole adapter

The preliminary design proposed the creation of a mounting point that could accommodate the use of three trekking poles or even whittled sticks as a tripod. The design was flawed in that it would have resulted in the blades contacting the poles if the setup was not properly executed. Furthermore, the design would have necessitated the use of three poles, which would not have been feasible for two individuals, who might have required their trekking poles for the erection of tents. The subsequent iteration of the design employed a single trekking pole with a combination attachment to the guy wires. This was achieved through the utilisation of a 3D-printed adapter that was affixed to the upper portion of the trekking pole, featuring apertures that permitted the formation of a hitch knot, thereby securing the trekking pole and simultaneously functioning as a guy wire to enhance stability. This configuration is illustrated in Figure 10. Additionally, a threaded wire was incorporated on the superior aspect to facilitate attachment to the yaw system.

Figure 10: CAD model of trekking pole adapter.

2.4.2. Pole

A 6 mil aluminium rod was utilised, which had a 2 mil hole through it. A lathe was employed to create a 2.5 mil diameter hole with a depth of 10 mils. The hole was then tapped at both ends to accept an M3 screw, with the addition of Loctite to secure it in place on one end of the pole. The final component is a tapered quenched steel piece, which is screwed to the aluminium pole (see Figure 11). The upper pole is threaded at its extremity to facilitate attachment to the yaw system. Additionally, an 8 mil diameter sleeve is incorporated to prevent slippage. Each rod is 20 cm in length and six rods are housed within the body, equipped with four pegs and a guy wire.

Figure 11: Two of the rods connected together.

2.4.3. Yaw system

The yaw system comprises an M6 threaded rod with an 8-millimetre sleeve, the purpose of which is to prevent the yaw system from slipping. This is illustrated in Figure 12. This is attached to a bearing within the turbine and an M6 coupling to maintain its position. The blades face downwind and rotate in the direction of the wind using the yaw system. The cone is employed to ensure the body's aerodynamic efficiency. The blades serve as the rudder, orienting themselves to the optimal angle of attack by capturing the wind, thereby maximising energy generation.

Figure 12: Visual representation of how yaw system works with concrete flooring bold at a substitute axle.

2.5. Main body and housing

The tube is a highly compact structure, as is evidenced by the 3D-printed housings, which are also compact and prevent any component from moving, solely through the use of a friction fit. The overall length of the folded body is 30 cm, with a diameter of 15 cm and a weight of 1.3 kg, including pegs, poles and guy lines. The blade has an extended span of 50 cm.

Acrylic was selected for this prototype to facilitate the user's ability to observe the internal components. A transparent acrylic piece with an outer diameter of 60 mil and an inner diameter of 56 mil was selected for the body, as illustrated in Figure 13. This material was chosen for its durability, as it can withstand multiple drops without shattering. However, it is susceptible to scratching, which is a limitation of this material. Consequently, future iterations will utilise alternative materials, such as carbon fibre, to enhance durability and ensure waterproofing. Additionally, the 3D-printed components will be replaced with alternative materials to reduce weight.

Figure 13: Complete body with two blades unfolded.

3. Experiment

The objective of this experiment is to ascertain the power generated by the wind turbine at varying wind speeds. This is tested at the optimal angle of attack, which the yaw system will automatically adjust to as this is where the wind is blowing with the greatest intensity. The scenario is straightforward: a simulated gust of wind is directed towards the turbine, with the blades positioned perpendicular to the wind's direction of travel.

The experimental procedure entailed ensuring a stable environment by testing all components within the system. The turbine is affixed to the tripod, as the pole is unable to function within the apparatus due to its necessity for ground penetration. The blades are oriented perpendicular to the direction of the wind, as this configuration is optimal for maximizing power generation. The fan is activated, and the turbine is positioned at a wind speed of 2 metres per second, as illustrated in Figures 14 and 15. The wind speed is recorded with a digital anemometer in close proximity to the turbine hub. The wind speed generated by the fan exhibits inconsistency across the blade span; therefore, the anemometer is positioned adjacent to the hub, where the wind speed is most pronounced. It is expected that the turbine will exhibit a consistent wind speed across the blade span when subjected to wind. However, testing it next to the turbine hub has been shown to increase the efficacy of the turbine. The power generated by the turbine is recorded by multiplying the voltage and current displayed on the MPPT charge controller. The turbine is then relocated to a position where the wind speed is increased by half a metre per second until it reaches 5.5 metres per second, which represents the maximum wind speed. The power generated is recorded at each stage, as illustrated in Table 1 and Figure 16.

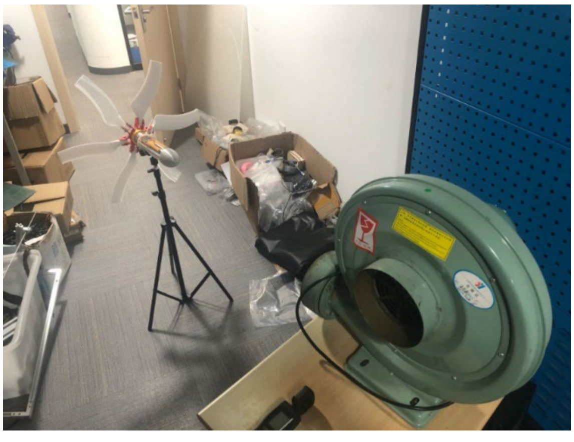

Figure 14: Experiment layout.

Figure 15: Power output at a windspeed of 4.5m/s.

Table 1: Wind speed, Power output and RPM of generator.

Wind speed (m/s)	Power output (W)	RPM of generator
2.5	0.12	611
3.0	0.29	837
3.5	0.41	1067
4.0	0.83	1202
4.5	1.65	1365
5.0	3.57	1543
5.5	7.83	1832

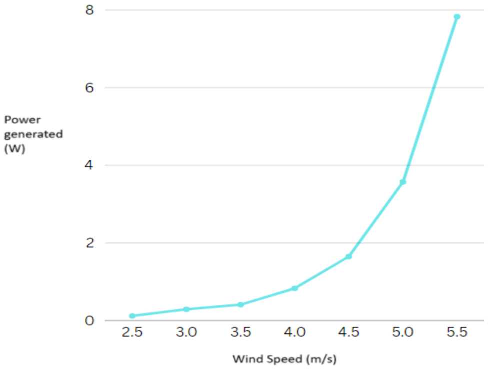

Figure 16: Graph of wind speed (X axis) and power generated (Y axis).

4. Discussions

The wind turbine is capable of generating a sufficient quantity of power at a wind speed of 4.0 m/s over the course of an hour. This is a reasonable wind speed in the UK, with an average of 8.3 knots, which is approximately 4.3 m/s. This will charge a 10000 mAh 5-volt power bank in one hour. This is sufficient to meet the power requirements of the power bank. The device is capable of producing speeds of 2.5 m/s and above.

This approach is effective and can be applied in a variety of contexts. In the context of camping and outdoor activities, the effectiveness of this approach is contingent upon the weight of the power banks required for the trip exceeding the weight of the portable wind turbine. In the absence of precise data, an approximation can be made based on the assumption that more than six power banks would be required for an expedition. However, it is important to recognise that every scenario is unique and therefore requires a bespoke solution. In the absence of wind, alternative solutions must be explored. The design is well-suited to camping applications due to its robust construction, which allows for the use of a stick as a pole in the event of a pole failure. Additionally, the blades can be disassembled and reassembled without the need for a screw, enhancing the design's versatility. It is recommended that these features be improved in subsequent iterations, including the implementation of enhanced waterproofing, optimised blade profiles, a reduction in size and weight.

With regard to the next stages of the design process, Modifications will be made to the blade-holding system. The utilisation of spring pins as a locking mechanism is an efficacious approach. Nevertheless, the width of this particular design can be reduced by employing an L-shaped blade and eliminating portions of the hub. Secondly, the blades are constrained by the utilisation of a 3D printer for the fabrication of compact turbines. It is optimal to produce blades with minimal thickness, akin to that of a fan blade. Further investigation will be conducted using existing fan blades, fluid dynamic simulators, and theoretical calculations. This will entail either modifying an existing fan to serve as blades or fabricating them from PVC, sheet metal, composite materials, or even timber. This will result in blades that are thinner, lighter and more compact, while also increasing efficiency.

The subsequent stages of the project will entail a redesign of the body. The design of the body will be modified to enable the blades to be folded into the body. The 3D-printed components will be remade, as they lack complete waterproofing. The body will be designed in such a way that the components are easily repairable, which is challenging due to the necessity for a compact and tight structure. This issue can be addressed by incorporating modules into the design, allowing for a more modular approach to the assembly of the body. This facilitates the removal and connection of specific components with the assistance of robust electronic connectors.

The concept of battery interchangeability has merit; it allows one battery to be charging while the other is discharging. However, this increases the overall weight of the system. An alternative solution would be to use a 3-meter cable connected to the device within the tent canopy. Such a configuration could render the device vulnerable to damage from a reduction in temperature, with the potential for water damage also being a concern. However, the next prototype will include a waterproof USB-C and USB-B charging port on the outside, allowing for the charging of devices in tandem with the power bank. It will also require the identification of a lighter and more powerful power bank, as well as the addition of insulation to prevent the electronics from being subjected to extreme cold. The use of MPPT controllers will prevent over- and undercharging.

5. Conclusion

In conclusion, this paper presents the design and creation of an efficient and effective portable power turbine. The device is capable of charging any electronic device with a power consumption of up to 100 Watts. The device is remarkably portable, weighing only 1.3 kilograms. Additionally, the device is relatively compact, with a diameter of 15 cm and a length of 30 cm. It is capable of generating power from minimum wind speeds of 2.5 m/s. This article contributes to the limited existing literature on small wind turbines. Further development is necessary to reduce the weight, size, and increase the efficiency of this portable turbine. With further development, it has the potential to become an even more viable source of generating power in off-grid areas.

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