Group 10101

GLOWING WIND!

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STEM High School for Boys
6th of October
Grade 10
Semester 2 (2023-2024)

Keywords: Savonius rotor - Wind energy - Light - Electricity - Recycled materials

ABSTRACT

Egypt's advancement is blocked by several Grand Challenges. This project addresses improving use of alternative energies, dealing with population growth and its consequences, improving the scientific and technological environment for all, and reducing and adapting to the effect of climatic change. The purpose of the study is to utilize wind energy to power light posts in STEM October school. The specific problem to be solved is the lack of energy availability to power lights at nighttime. A Savonius wind turbine was constructed using recycled, locally available materials. The prototype underwent specific tests to ensure it effectively fulfilled design requirements, including the ability to produce 150 Joules in 5 minutes, in addition to storing and using this energy in a useful application. Some negative results were present but were overcome through modifications to achieve the design requirements. Major findings, after gathering the results, included the prototype's ability to produce the aforementioned amount of energy. Major conclusions confirm the prototype's effectiveness for overcoming the problem to be solved and that all problems in the prototype were successfully overcame. In addition, scaling the prototype could significantly contribute to solving Egypt's Grand Challenges and the specific problem of lack of energy.

INTRODUCTION

Egypt encounters several grand challenges that impede its development in different fields. At an annual rate of 1.57%, Egypt's population has been rapidly growing, reaching 114.5 million in 2024 (Worldometer, 2024). This rising population leads to increased energy consumption, which contributes to climate change due to the dependency on fossil fuels that results in greenhouse gas emissions. In 2022, approximately 88% of energy produced in Egypt came from non-renewable sources (IRENA, 2023), **as shown in Figure 1**. Thus, the need for improving alternative energy sources is significant. In addition, improving the scientific and technological environment is crucial for developing innovative renewable energy technologies.

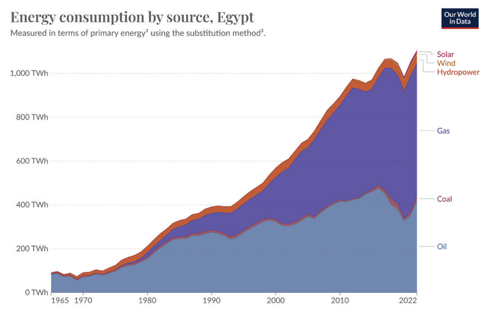

Figure 1: Energy generated in Egypt by source.

Improving alternative energy sources determines the problem to be solved, lack of energy availability to power lights at nighttime in STEM October school. Solving this problem, which increases energy consumption and reduces schedule control, would result in decreased greenhouse pollution, increased safety, and discouragement of wild animal activity.

In order to tackle the problem, prior solutions, including Al-Zafarana Wind Farm and Oklahoma Medical Research Foundation (OMRF) Venger rooftop wind farm, were studied to benefit from their advantages and deal with their downsides. Al-Zafarana Wind Farm utilizes 700 horizontal-axis wind turbines of different models (Ministry of Electricity and Renewable Energy, 2016). A point of strength of Al-Zafarana wind farm is usage of variable blade pitch technology, which increases its performance. Although its large capacity, about 745 MW, the farm faces grid integration complexities, such as grid stability management and voltage regulation which is a point of weakness. In the US, the OMRF Venger rooftop wind farm utilizes 18 vertical axis wind turbines (VAWTs) that has a relatively large capacity of 4.5 kilowatts each (OMRF, 2012), which is an advantage, in addition to taking advantage of omni-directional air currents. A disadvantage of this farm is the high wind speed required to start operating, 4 m/s, especially for urban conditions.

After searching prior solutions, it was determined that the selected solution should entertain a criteria of design requirements, where it must encompass the ability to generate at least 150 joules at a maximum period of 5 minutes, and a minimum efficiency of 10%. The overlap ratio must also be in the range from 20% to 30%, experimentally proved to be optimal by previous research.

The selected solution is to construct a Savonius vertical axis wind turbine, chosen for its reliability, carbon neutrality, material minimalism, and structural simplicity, in addition to omnidirectionality and high maintainability, which increased the solution's viability. The materials used in the prototype were chosen to meet the design requirements.

MATERIALS & METHODS

Name	Quantity	Figure	Description
Plastic bucket	2 buckets		Plastic buckets were cut into halves to form the blades.
Polystyrene foam	3 sheets (60 × 60 cm)		Foam was used to make the bases.
Wooden planks	4 planks 2 (100 × 10 cm) 2 (70 × 10 cm)		Wood planks were used to construct the frame (holder) of the turbine.
Broom stick	1 stick (120 cm)		A broom stick was used as an axis.
DC motor	1 motor		A DC motor was used as a generator to convert mechanical energy to electricity.
Gears	1 large gear 1 small gear		Two gears, with a ratio 4:1, were used to increase the number of rotations.
Ball bearings	2 bearings		Ball bearings were fixed to the frame to hold the turbine suspended.
Lithium-ion battery	1 battery		Lithium-ion battery was used to store the generated electricity.

Table 1: The materials used in the prototype

Methods

1. A 3D model of the prototype, **shown in Figure 2**, was made to help in construction and simulation.
2. Two plastic buckets were cut into halves to form the blades with a height of 25 cm and a diameter of 27 cm.
3. Circular bases of a diameter of 52 cm were made of polystyrene foam slabs.
4. Glue was used to fix the blades to the bases and to connect the two layers of the turbine.
5. A wooden broomstick was inserted in the turbine's center through the foam slabs to form the shaft.
6. Two foam squares of side length 15 cm and thickness 3 cm were connected to the two ends of the turbine using white glue to support it.
7. A hole of diameter 2.5 cm was drilled in two wooden planks of length 62 cm and width 10 cm.
8. Ball bearings were secured in the previous planks using nails **as shown in Figure 3.**
9. Two wooden planks of length 100 cm were connected with the aforementioned planks to construct the frame of the turbine.
10. The turbine was installed in the frame, **as shown in Figure 4**, and bearings were adjusted to suspend the shaft well.
11. Two gears, with a ratio 4:1, were used. The larger one was connected to the shaft and the smaller to a generator, with both connected via their teeth.
12. The generator was fixed to the frame, **as shown in Figure 5**, so that it rotated with the turbine.

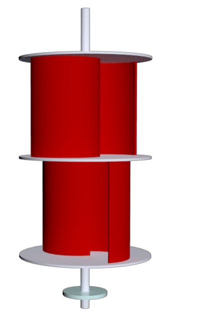
Figure 2: A 3D model of the prototype


Figure 3: Ball bearing after fixing it to the frame


Figure 4: The turbine installed in the frame


Figure 5: The generator fixed to the frame

Test Plan

A set of criteria were set to ensure the prototype's feasibility, allowing improvement on points of possible weakness.

1. A multimeter was used, **as shown in Figure 6**, to measure the current and voltage every second for 5 minutes. The average for voltage and current was calculated using a computer program. Then, the watt value was calculated with the equation W = VI, where W is power, V is potential difference, and I is current intensity, to make sure it fulfills the minimum, 0.5 watts.
2. To calculate efficiency, power input was calculated using the equation $P_{in} = \frac{1}{2}\rho A V^3$, where P_{in} is power input, ρ is air density, A is the area of the turbine blade, and V^3 is wind velocity. Overall turbine efficiency was calculated by the equation $C_p = \frac{P_{out}}{P_{in}}$, where C_p is the power coefficient, or turbine efficiency, P_{out} is the power outputted, measured using the previous criteria, and P_{in} is the power inputted. C_p value was made sure to not be less than 0.1.
3. A battery was charged by using the prototype's energy output, then a light-emitting diode (LED) was connected to the battery, **as shown in Figure 7**, to check if the energy produced could be successfully used in other applications.
4. The overlap ratio was calculated to ensure if it fell in the optimal range between 20% and 30%.


Figure 6: The multimeter connected to the generator

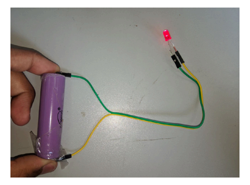
Figure 7: The LED lighted by the charged battery

RESULTS

Negative Results:

Colloidal resin, the substance used at first to stick the blades, ate away the bases, which decreased aerodynamic efficiency. One of the blades wasn't fixed well to the bases, which led to its breaking when exposed to a high-speed wind. The gears were first positioned incorrectly, which led to the stopping of the smaller gear, thus leading to the loss of energy.

Posititve Results:

The prototype fulfilled the design requirements, where it generated an average of 1.47±0.11 watt over a span of 5 minutes, or a total of 441±33 joules. The efficiency was calculated to be (17±1.3)%, with a maximum of 7.28 volts and 0.58 amperes achieved. **Figure 8** displays the graph of potential difference values, while **Figure 9** presents the graph of current intensity. The overlap ratio was calculated to be (29+0.52)%, lying in the optimal range of 20% to 30%.

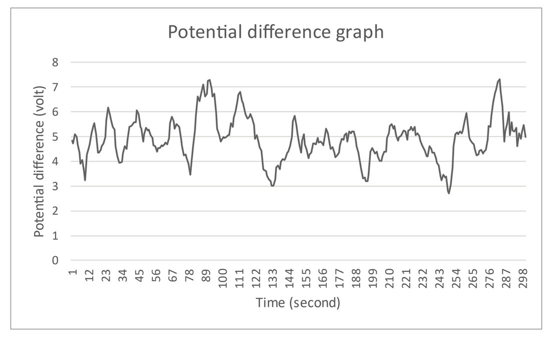

Figure 8: Potential difference values

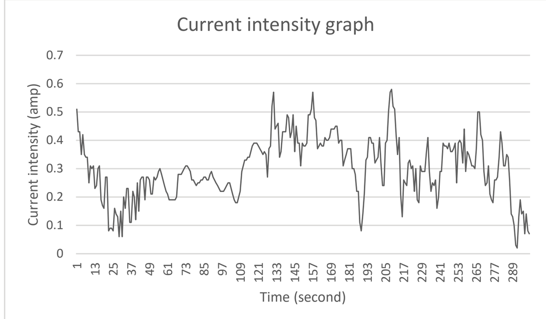

Figure 9: Current intensity values

ANALYSIS

Effect of blade overlap on blade efficiency

The prototype's efficiency was optimized by overlapping the blades over each other, as **shown in figure 10**. This improved aerodynamic flow, as it gives incoming wind currents a path to follow unto the concave side of the right blade, further increasing drag force producing the primary torque. **Figure 10** shows an approximation of the distribution of an incoming air current, where air approaches at θ=0° in the upper drawing and θ=90° in the lower drawing.

In the lower drawing, as discussed in PH.1.09, separation regions are caused by the detachment of the boundary between flowing fluids, in this case air, and the object, in this case the blade. It causes turbulent flow in those spots, symbolized in the figure with eddies

Upon the interaction of a fluid with an object, depending on the shape of the object and texture, drag and lift forces result. Drag is in a direction parallel to the flow, while lift is perpendicular to the flow. In the prototype, drag force is classified into two: opposing and primary. Primary drag is in the direction of main rotation, and opposing is in the opposite direction. The net drag force is their difference, and it represents the real force which will affect the turbine. Meaning that minimizing opposing drag and increasing primary drag both increase turbine efficiency. The net drag force results in torque, which rotates the turbine, in addition to lift force resulting from the recirculation of air in the upper drawing and current distribution in the lower drawing, due to the overlap opening. **In figure 10**, currents 3 and 4 result in primary drag in both drawings. In the upper drawing, only current 5 causes opposing drag force, while in the lower drawing, currents 2 and 5 result in opposing drag force. (Simon Prince, 2020, pp. 2-4)

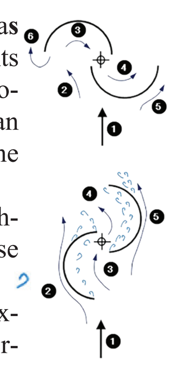
Figure 10 effects of blade overlap on the distribution of incoming air currents.

The overlap ratio is a relation between the diameter of the base and the overlap distance. The overlap distance is the length of the diameter part that's in the overlap. It was calculated using the following equation:

$$\alpha = AC + BD - D_{AB} = 2d - D_{AB} = 2 \cdot ((27 \pm 0.1)\ cm) - (42 \pm 0.1)\ cm$$
$$= (12 \pm 0.22)\ cm$$

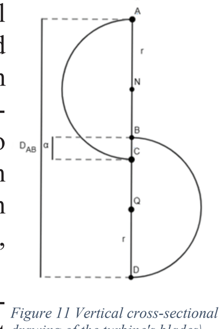

Figure 11 Vertical cross-sectional drawing of the turbine's blades

As represented in figure 11, AC and BD are diameters, and since they are equal, we equate them to 2d, and is the distance between point A and B.

The D_{AB} overlap coefficient/ratio can be calculated by the following equation (Khandakar Niaz Morshed, 2013, pp. 4):

$$C = \frac{\alpha}{D_{AB}} = \frac{(12 \pm 0.22)\ cm}{(42 \pm 0.1)\ cm} = 0.29 \pm 0.0052 = (29 \pm 0.52)\%$$

where C is the overlap coefficient and α is the overlap distance. Previous research papers have shown by experimentation that the optimal overlap coefficient range is between 20% and 30%, (Mohd Zamri Ibrahim, 2013, pp. 3) thus thecoefficient is in such optimal range. Past papers have shown that optimal overlap ratios can increase efficiency by upwards of ~28%. (J. Thiyagaraj, 2021, pp. 6)

Power coefficient calculation

In order to ensure the prototype fulfilled design requirements and had relatively high efficiency, the power contained in the wind at that time had to be calculated, which 100% of it would be acquired as electricity if no loss of energy occurred. To calculate it, the swept area must be calculated, or A_s. First, the height of a blade was measured, then multiplied it by 2 since a double layer turbine is used.

$$h = 2 \cdot h_b = 2 \cdot ((25 \pm 0.1)\ cm) = (50 \pm 0.2)\ cm$$

Where h_b is the height of a blade. And h is the total height of the double layer, excluding the separating base.

Then, A_s was calculated using the following equation: (Khandakar Niaz Morshed, 2013, pp. 4)

$$A_s = h \cdot D_{AB} = (50 \pm 0.2)\ cm \cdot (42 \pm 0.1)\ cm = (2100 \pm 9.78)\ cm^2$$
$$= (0.21 \pm 0.00098)\ m^2$$

Wind velocity was retrieved from a wind map, which showed that air speed, or v_w, was 4 m/s at the time of the test plan in STEM October school.

Using all aforementioned calculations and measurements, the power contained in wind, or, P_w was calculated using the equation: (Alexander Kalmikov, 2017, pp. 4)

$$P_w = \frac{1}{2} \cdot \rho_w \cdot A_S \cdot v_w^3 = \frac{1}{2} \cdot 1.293 \frac{kg}{m^3} \cdot (0.21 \pm 0.00098)\ m^2 \cdot \left(4 \frac{m}{s}\right)^3$$
$$= (8.69 \pm 0.04)\ watt$$

where P_w is wind power and ρ_w is the density of the wind, with an average value of 1.293 $\frac{kg}{m^3}$ at a temperature of 273 K and a pressure of 101.325 kPa. (Nasa, 2019)

Using P_w, the coefficient of power, or efficiency in terms of wind turbines, was able to be calculated using the following equation: (Khandakar Niaz Morshed, 2013, pp. 4)

$$C_p = \frac{P_t}{P_w} = \frac{(1.47 \pm 0.11)\ watt}{(8.69 \pm 0.04)\ watt} = 0.17 \pm 0.013 = (17 \pm 1.3)\%$$

where C_p is the coefficient of power, is P_t power outputted from the wind turbine, and P_w is power contained in wind.

Rotations per minute increase by gear ratio

As discussed in PH 1.05, gear ratios increase rotations per minute. Two gears were 3D printed from a fabrication lab using PLA+. To calculate the gear ratio, the amount of gear teeth on each was counted, where the larger gear had t_l =32 and the smaller t_s =8.

By dividing the larger gear teeth number by the smaller, the gear ratio is obtained:

$$G_r = \frac{t_l}{t_s} \cdot 100 = \frac{32}{8} \cdot 100 = 400\%$$

This means that the gear ratio quadruples rotations per minute.

Inner-working of motor

A generator was used to generate electrical energy from rotation. **Figure 12** shows a cross section of a generator. The prototype causes the rotation of rotors, which are connected to windings. Windings are bundles of copper wires, with magnets on the outside in the figure, but inside in this case, for electric current to pass through. Upon rotating the windings through torque transmitted by the rotors, the torque, or kinetic energy, is converted into electrical energy via electromagnetic induction. This is due to the switching of specific parts of the windings from the south pole into the north pole and vice versa, pushing and pulling loose electrons in the copper, which generates an electrical current. (eia, 2022)

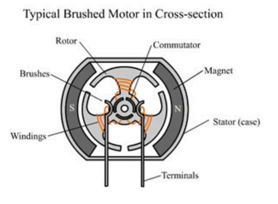

Figure 12: Cross-sectional area of a motor.

L.O.	Description	L.O.	Description
PH 1.02	PH 1.02 explains the different types of forces, such as drag and lift, which the prototype utilizes to generate torque.	**SS Mo.1**	Wind velocity was retrieved from online GIS services, which were primarily discussed in SS module 1.
PH 1.09	The blade overlap was designed with laminar and turbulent flow in mind, which was specifically discussed in PH 1.09.	**CS 1.09**	CS.1.09 explains the thought process of writing program code, thus It was essential for calculating multimeter uncertainty and the readings average.
PH 1.05	The mechanical advantage of the gears was calculated using PH 1.05, as it discussed simple machines, such as gears, and their mechanical advantages.	**CH 1.01**	CH 1.01 explains how to deal with uncertainties and significant figures, which were essential to decreasing measuring errors, and calculating multimeter error.

CONCLUSIONS

The challenge addressed in this project is finding an alternative source of energy to power lights at nighttime in STEM October school. The solution chosen was building a Savonius vertical axis wind turbine to generate the needed electricity. Despite negative results, the prototype successfully achieved the design requirements. The generated electricity was approximately 441 joules in 5 minutes and its efficiency was about 17% by using only recycled or natural materials. This proved the prototype's ability to light LED, as was done in the test plan. In comparison with the studied prior solutions, El-Zafarana Wind Farm, the prototype achieved its points of strength and avoided its points of weakness. The prototype has a lower cost, and the generated electricity can be stored and then used easily with the storage battery system.

RECOMMENDATION

Real-life applications

The recommended location to apply the solution is STEM High School for Boys - 6th of October, **shown in Figure 13.** The school contains many lamp posts which are either unworking or turned off in order to decrease energy consumption. Installing the turbine on these lamp posts will provide a free source of energy as well as better lighting in the area. The dimensions of the turbine are as follows: the turbine's height will be 100 cm and the base width will be 52 cm. The blades will be 25 cm in height and 27 cm in diameter. The turbine will consist of 3 layers of blades.

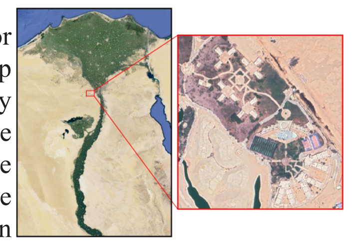
Figure13:Location of STEM October school

Fibonacci-spiral shaped blades

The Fibonacci spiral shape is found in many occurrences in nature and is thus a result of billions of years of evolution. It follows the shape of the Fibonacci sequence, which adds each two numbers in the following way: 1, 1, 2, 3, 5, 8, 13, 21 …. The shape makes multiple circles with radii of the sequence's numbers, **as shown in figure 14**. Multiple papers have been published on the effect of making wind turbines Fibonacci shaped, and experimentation showed that using Fibonacci-shaped blades can increase efficiency by 17.4%, at a tip speed ratio of 1, over standard Savonius blades. Applying this will require using materials with high deformity, such as thin iron metallic sheets, as iron can be easily permanently bent into required shapes.

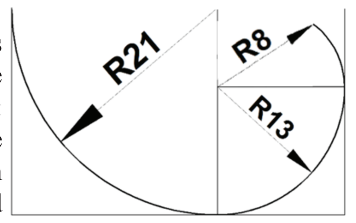

Figure14 suggested shape for the recommended fibonacci-spiral shaped blades

Implementation of wind deflectors

Using a deflector in front of the returning blade, **as shown in Figure 15**, which causes opposing torque, can lead to an increase in efficiency by decreasing drag force acting on such blade, while deflecting wind onto the advancing, or primary torque blade, further increasing acceleration. Previous research papers have shown that using a plate with 0.9 porosity increased efficiency by an average of ~10% compared with a solid plate. Putting the deflector at a 90° angle with incoming air also improves efficiency. A relation between the length of the deflector and the diameter of the turbine's blades was also found, where the optimal L/D ratio was found to be 0.99. The optimal height of the deflector was also related to the diameter, and via experimentation, the optimal h/D turned out to be 0.257. By substituting using the prototype dimensions, where D = (0.42± 0.001) m, then L = (0.42 ± 0.00099) m and h = (0.11 ± 0.000257) m.

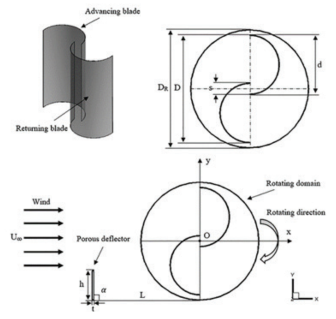

Figure 15 vertical cross sections of a wind turbine with a porous deflector

LITERATURE CITED

1. Albani, Aliashim & Ibrahim, Mohd Zamri. (2013). Preliminary study and development of prototype of Savonius wind turbine for application in low wind speed condition in Kuala Terengganu. International Journal of Scientific & Technology Research. 2. 102-108. 10.17605/OSF.IO/BMQWY.
2. Damota, Javier & Rodriguez, Juan de Dios & Couce, Antonio & Galdo, M.I.. (2021). Proposal of a Nature-Inspired Shape for a Vertical Axis Wind Turbine and Comparison of Its Performance with a Semicircular Blade Profile. Applied Sciences. 11. 6198. 10.3390/app11136198.
3. Eshagh Nimvari, M., Fatahian, H., & Fatahian, E. (2020). Performance improvement of a Savonius vertical axis wind turbine using a porous deflector. Energy Conversion and Management, 220, 113062. https://doi.org/10.1016/j.enconman.2020.113062
4. Kalmikov, A. (2017). Wind Power Fundamentals. Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology. https://web.mit.edu/wepa/WindPowerFundamentals.A.Kalmikov.2017.pdf
5. Morshed, K.N., Rahman, M., Molina, G. et al. Wind tunnel testing and numerical simulation on aerodynamic performance of a three-bladed Savonius wind turbine. Int J Energy Environ Eng 4, 18 (2013). https://doi.org/10.1186/2251-6832-4-1
6. Prince, Simon & Badalamenti, Carmine & Georgiev, Dimitar. (2020). Experimental investigation of a variable geometry vertical axis wind turbine. Wind Engineering. 45. 0309524X2093513. 10.1177/0309524X20935134.

ACKNOWLEDGEMENT

We want to start by expressing our gratitude to Allah for enabling us to complete this productive project. Secondly, we would like to express our gratitude to everyone who helped us along the way, particularly the capstone general Mr. Hesham Abd El-Razek, our capstone leader Mrs. phoebe Barsom, our capstone teacher Mrs. Samia, as well as everyone else who contributed to making this project successful. We could not have achieved these successes without all of the help we received.