



A HYBRID VERTICAL AXIS WIND TURBINE WITH SAVONIUS BLADES FOR ENERGY GENERATION

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01 ABSTRACT

Egypt suffers from interconnected grand challenges that have an impact on the country's economy, environment, and social life. To illustrate: recycling wastes, arid areas, urban congestion, and public health. Those hinder Egypt's efforts to develop sustainably. The problem that connects all of this is the reliance on diesel generators that causes many more problems like pollution, climate change, and even soil corruption, which then could be solved by using more sustainable energy sources, such as solar, wind, and hydropower. After research that was responsible for finding a solution to this problem, the chosen solution is to build a portable vertical-axis wind turbine. Compared to solar and hydro, the wind turbine was chosen for the flexibility in location since it does not need strong water, such as rivers, nor a large area where there are no shadows. The prototype was constructed with recycled materials to help the environment. Further to ensure the success of the prototype, several design requirements were stated such that the volume of the prototype doesn't exceed 0.5m³ and produces 0.04kWs in at most 5 minutes. The prototype was then tested, and results measured the success of the project, managing to produce an average of 100 joules, achieving all design requirements.

02 INTRODUCTION

Egypt encounters several interconnected challenges, many of them, are crucial to be solved, and if not it will hinder Egypt's development, crucial factors like health, energy and poverty crises may delay Egypt from developing, the main focus for this project was solving the energy challenges, improve the use of alternative energy, improve the scientific and technological environment for all, and reducing air, water and soil pollution, those were the main grand challenges that this project solves, mainly Egypt suffers from the use of conventional energy sources going up to 88.5% fossil fuel use (2022 est.) and using only 11.4% renewable energy, Egypt has been driven for oil, gas and other conventional energy sources as shown in Figure .01. All of these are connecting to the problem to be solved, which is reducing the use of diesel motors, the use of diesel motors in areas that have unreliable energy grid, industrial zones and during frequent power outages, has been going up in recent years, which after being a targeted reduction in the reliance, it will play a crucial role in improving health, and energy inequity in arid areas, and overall improving Egypt's renewable energy grid by supporting it more with renewable energy sources.

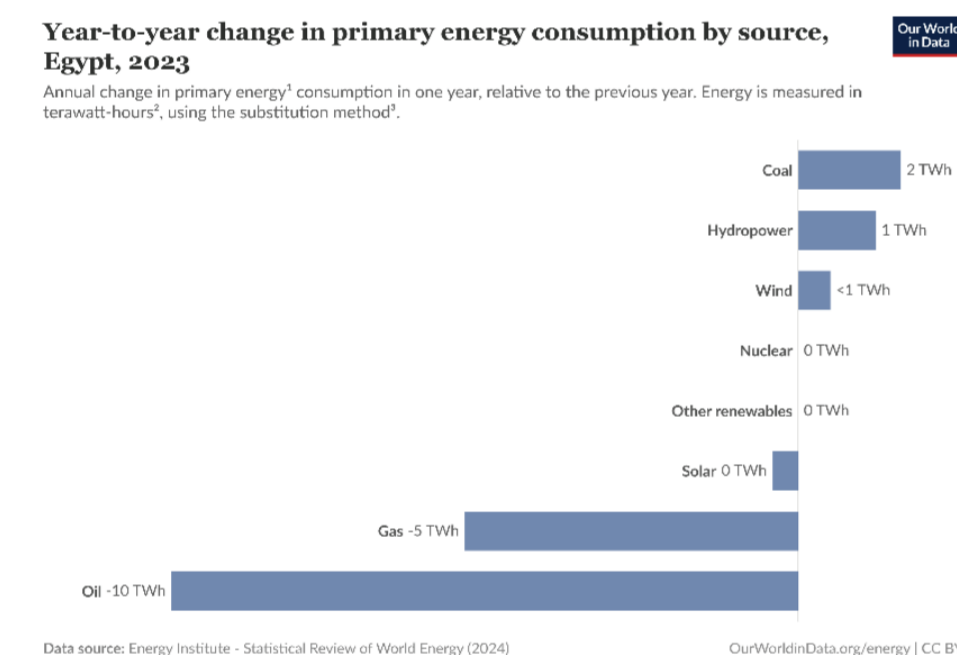


Figure .01: annual energy consumption

Many efforts have been focus to solve this problem before, producing beneficial references to work with and improve, starting from the Benban solar park, Zafarana wind farm and the high dam in Egypt, although all of these solutions are great, and they solve the energy crisis, but each one of them has a point of weakness, starting off with the high dam, which has soil fertility loss, environmental impacts and sediments accumulation, moreover, the Zafarana wind farm, has many energy storage limitation, and shorter lifespan, due to being a horizontal axis wind turbine.

Furthermore, after researching, about different types of energy harvesting systems, there were two main solutions, either doing a vertical axis wind turbine (VAWT), or doing a hydropower station, the hydropower station wasn't chosen due to some demerits, which makes VAWT more suitable than hydropower, is that VAWT works in diverse environments, while the hydropower, needs environments that have rivers or water sources, making the VAWT, more suitable as solution for portable use in any place.

Over and above that, the design requirement for this selected solution, was then chosen, to increase the features in the VAWT, firstly to produce 0.04kWs in at most 5 minutes, or in other words produce 40 joules of energy in at most 5 minutes, secondly to be less than 0.5m³ in volume, and be less than 5kg, just to ensure it is easy to carry out, being able to store energy for long-term availability, and the most requirement part is to have the ability to self start under low wind speeds, providing a device that could work in any type of environment. By integrating the selected problem that was going to be solved, providing the type of energy harvesting system, and selected design requirements, the solution was then ready to be produced, and selected, which is a vertical axis wind turbine with savonius blades, by modifying old wind turbines, and using this blade design approach, that way it has the starting capability, the portable compact design, combined with a lithium-ion batteries to store energy, and the ability to be large scaled and farmed easily, achieving all the design requirement and solving the problem.

03 MATERIALS & METHODS

Methods:
The prototype was carried out as the following:

- Cut a frame in the shape of a circular base that is made of bucket, to form the base.
- Using the plastic water tank, to cut the blades of the turbine, after stabilizing using a wooden stick.
- The stick was then stabilized into a bearing to help in rotation.
- The big gear was connected to the second gear, under the base of the prototype, to the generator.
- The wires from the generator was than connected to the battery holder.

Test Plan:

- Calculate the resistance in the generator, using a multimeter, to test the power over 5 minutes.
- The blower created, a wind simulation to test the blades whether they could withstand high wind speeds.
- The energy storage was tested by charging a battery for 5 minutes, then measuring with a multimeter.
- The prototype was measured to determine whether it achieved the compact design or not (Volume <0.5m³).

Table .01: Table of Materials

Item	Usage	Price	Source	Image
Wooden sticks	Stabilizing	60	Recycled	
Buckets	Base	30	Recycled	
Ball bearing	Smooth rotation	15	Amazon	
Battery holder	Holding battery	20	Amazon	
Lithium-ion battery	Charging	35	Electronics store	
Generator	Energy generation	340	Electronics store	
Gears	Increase RPM	100	Electronics store	
Total		600		

04 RESULTS

After constructing and building the prototype, measurements were taken every 10 seconds, both the resistance, voltage, power and energy the results were recorder, in Table .02, showing how voltage change every 10 seconds, while to be accurate a datasheet for the multimeter were used, which states that the error in voltage is (±0.5% +2) volts, meanwhile the resistance error is (±0.8%+2)ohm, the power was calculated by dividing the **voltage squared** over the **resistance**, and the energy were calculated by multiplying the **last record** by the time which is **300 second**. After the first trail, it showed several negative results, which couldn't satisfy the design requirement, and produced voltage in micros, then a second trail was followed with positive results, and solutions to those negative results as shown in the following table, the power output in one minute has met the design requirement.

Negative results:

1. Turbine stayed stuck, and needed more wind speed to start spinning.
2. the energy output wasn't stable.

Positive Results:

1. The gap between the blades helped to create more pressure over the blade, and work better in low wind speeds.
2. the VAWT self-started under unstable wind conditions.
3. the prototype being lightweight (1.3kg) helped the prototype to be portable and rotate rapidly.

The negative results were then solved by, firstly creating the gap to help the prototype start spinning, and using a gear system to help to utilize the power output.

Table.02: Table of Multimeter data power and energy calculations

Time (S)	Voltage (V)	Resistance (Ω)	Power (W)	Energy (J)
1-10	7.129 ±0.038	99.1 ±1.0	0.513 ±0.011	153.9 ±10.44
10-20	7.079 ±0.037	99.1 ±1.0	0.506 ±0.010	151.8 ±8.34
20-30	5.059 ±0.027	99.1 ±1.0	0.258 ±0.005	77.4 ±66.06
30-40	6.726 ±0.036	99.1 ±1.0	0.456 ±0.009	136.8 ±6.66
40-50	8.078 ±0.042	99.1 ±1.0	0.658 ±0.013	197.4 ±53.34
Average	6.814 ±0.036	99.1 ±1.0	0.4782 ±0.010	143.46 ±29.08

05 ANALYSIS

The prototype solves many grand challenges, after solving the problem to be solved, which is reducing the use of diesel generators, solving energy limitations in Egypt, and pollution, due to the decreased awareness about energy resources, the prototype helps by using alternative and renewable energy sources such as wind, instead of non-renewable energy sources, like coal and petroleum based on ES.1.10. As shown from the results, on the previous section, trails has shown multiple of results, to illustrate a variety of positives and negatives. The positive results could be concluded in a few statements. Firstly, the self-start feature, as the savonius blades were integrated, ensuring the self-start feature. This is because the savonius blades doesn't require any lift force, as in PH.1.10, making the blades be affected by any small pressure difference cause by a breeze of air, causing the blades to start rotating, as shown in the following equation:

$$\Delta P = P_{front} - P_{back} > 0$$

Equation .01

After the first trial, it was noticed that the turbine could self-start, but sometimes it stayed stuck for a while, due to this negative result, a gap between the blades with an average of **1cm ± 0.4cm** was created, as shown in the next Figure.02, that is because it will increase the pressure over the front face of the blade, meaning that the pressure difference will increase, causing the blades to rotate much faster under low wind speeds. Furthermore, the prototype was going too fast, and it needed more stabling to work, due to that two sticks were used to help the prototype to be more stable, and using ES.1.08. New recycled material were used based on their physical and engineering properties, that way it maintained the lightweight effect while keeping it strong and stable.

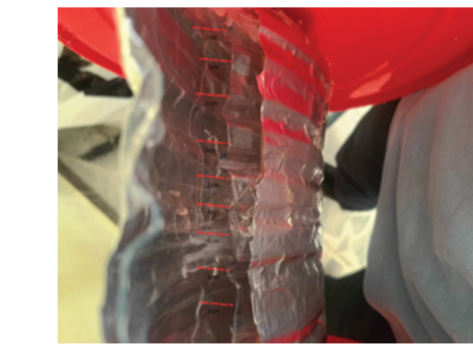


Figure .02: Gap in blades

Moreover, the generation of energy has been unstable in the first trail, that is because the turbine couldn't produce the required rpm, to generate enough power by the generator, so a gear system was appended in the turbine, based on the law of gearing as following:

$$\frac{N_2}{N_1} = \frac{\omega_1}{\omega_2}$$

Equation .02

Which states that when increasing the number of teeth in the first gear, and decreasing it in the second gear, the rotational speed will be maximized, so a gear ratio of 1:5.5, meaning that each time the first gear completes one rotation the small gear will complete 5.5 rotations. To calculate the power output, from the turbine, based on CH.1.14, which states that the power equals the multiplication of intensity and voltage. And to apply the same conditions to the measurement, the resistance of the circuit, which was measured 99.1ohm, was a constant across the circuit, then the intensity equals the voltage over the resistance, that is why the power output now equals the following equation:

$$P = \frac{V^2}{R}$$

Equation .03

The average power output over a course of 50 second, was 0.47 watts, with an increasing voltage, power, energy, and efficiency, by increasing the wind speed, across this trail, as the following Figure .03 represent, the power output was going up, that is because across the trail, the wind speed was increasing using a wind blower, until reaching the maximum output of the wind blower where the energy and power stayed constant across the trail, using MA.1.07 to model this graph, and to get the amount of energy produced, the following equation was used:

$$E = P \cdot T$$

Equation .04

by substituting the equation, assuming that the power will stay constant after the second 50, then the energy output after 5 minutes of working, will be **143.46 ± 29.08** Joules, which satisfies the design requirement, that was set earlier.

The efficiency of the wind turbine should be calculated to know whether this approach of constructing such a prototype is a positive thing or not. The reference point to the efficiency is the Betz limit theory, it states that a wind turbine can't capture more than **59.3%** of the kinetic energy of the wind, meaning that the efficiency limit is **59.3%**. To calculate efficiency there were two equations used, the first equation is the efficiency equation as follows:

$$\eta = \frac{Output}{Input} \cdot 100$$

Equation .05

The output power is the amount of power produced by the generator, but the input is the amount of kinetic energy that the wind could capture, and this was calculated by the following equation:

$$P_{wind} = \frac{1}{2} \cdot \rho \cdot A \cdot V^3$$

Equation .06

To calculate the average efficiency, average voltage and voltage was calculated, to produce the average power, then calculate the input power, setting the air speed to **4m/s²**, then the input power is **2.43** watt, which is then substituted to get the following equation with an efficiency of **19.34 ± 4.14%**.

$$\eta = \frac{0.47}{2.43} \cdot 100 = 19.34\%$$

Equation .07

After this the prototype has been able to meet the design requirement, storing and producing the amount of energy needed, while still maintaining the compact portable design.

06 CONCLUSIONS

From the tests, results and analysis, the following was concluded, the prototype has achieved all the design requirements, achieving the desired power and energy output, with an average of 0.65 watts per second, while maintaining the compact design in volume and weight, with a volume of less than 0.5m³ and a weight of nearly 1.3kg, built with recycled waste material, reducing the effect of climate change, and improving the electric grid in Egypt, compared to other prior solutions, which has bad effect on the environment like the high dam, miss the storage limitations like Zaffarana wind farm, or miss the portable compact design like the Benban solar farm. Achieving an efficiency of 19.34%, where the limit of the efficiency is 59.3%, making this project successful in every aspect.

07 RECOMMENDATIONS

There aren't any perfect or complete prototype, and every prototype needs some continues adjustments, to help improve it and get the most out of it, those are some recommendation that will help this project to be more nearly perfect.

Large Scale:

1. Using Spherical Roller Bearings (SRBs).
2. Using Permanent Magnet Synchronous Generator (PMSG).
3. Improve the curve of the blades and its dimensions.
4. Using plastic that has low weight and high strength like carbon fiber or reinforced composites.

Small Scale:

1. Combine H-Darrius blades with the Savonius.
2. Add Battery Managent System for ease of use.
3. Design modular blade attachments.

08 LITERATURE CITED

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09 FOR FURTHER INFO

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