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Construction of a helical vertical axis wind turbine for electricity supply

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ABSTRACT
In an effort to find solutions for global energy crisis, an analysis on a helical vertical axis wind turbine was conducted with the consideration of renewables and energy efficiency. This study was carried out in two steps: the realization of the analytical calculation of a helical wind turbine power output which then informed the design and construction of the rotor blades. The project particularly aimed to address its use as the electricity supply for residential properties or any other places with less ideal economy conditions. The uncomplicated and highly accessible mechanism using basic materials is to give people to have a viable option on their own electricity production.

KEYWORDS
Helical wind turbine; construction; blades design; electricity supply

1. Introduction

Wind energy is a clean and inexhaustible energy source widely used as a working fluid for wind farms for centuries. However, its use as a means of electricity supply began modern era due to the rise of environmental concerns and fuel resources issues. The global demand for sustainable and renewable energy has created the necessity for research and the development of new technology. Hence, the wind energy has been the focus of the industry and has considerably grown its use but just in a large scale production. In recent years, significant increase of more efficient, larger and expensive horizontal axis wind turbines (HAWT) appeared to create onshore and offshore wind-turbine fields [1].

This study aims to produce electricity on a lower scale by using a small wind turbine in order to generate a house-hold electricity supply and build a cost-effective and accessible turbine for people who need an alternative option to cover their own electricity demand. This report presents the rotor blade design, turbine construction and the results of the experimentation of a helical vertical axis wind turbine (VAWT). These turbines come with a few specific advantages over the horizontal ones, and those advantages make this kind of turbine a better option in a city or more challenging locations. Key features and its explication are described below:

- **Work speed range:** The VAWT starts to work under lower wind speeds (about 3 m/s) and can still work on high wind velocities (about 40 m/s).
- **Capturing all wind directions:** Such turbines can catch wind in all directions without requiring the heavy and expensive directional mechanisms.
- **Efficiency over higher turbulence levels:** The HAWT needs an axial wind incidence on the blades. Therefore, when wind turbulence increases, the efficiency decreases. However, VAWT catches the wind in all directions, so the change of wind directions, which is common in cities, does not affect its efficiency.
- **Turbine size:** The mechanism of VAWT is simpler and much smaller. HAWT can be over 30 m high and 20 m diameter. VAWT is approximately 3 m high and 1.5 m diameter.
- **Construction, maintenance and transportation costs:** As mentioned the VAWT is simpler and smaller therefore, the construction and maintenance are not complicated and due to the smaller scale, the cost for transportation is significantly lower than HAWT.
- **Reduced noise pollution and visual disturbance level:** This operating mode helps the helical vertical axis wind turbine make less noise (about 50 DB) and its twist geometry eliminates the flickering moving shadows casted by the blades.

The wind energy is the kinetic energy of air in motion. When such energy passes through the turbine rotor, the kinetic energy is transformed into mechanical energy which makes the blades starting to move. The power output of the wind turbine is given by

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Equation 1:

$$P = \frac{1}{2}\rho A v^3 \eta_T \eta_G \tag{1}$$

Where:
P = Power output (W)
A = Sweep area (m^2)
ρ = Air density (Kg/m^3)
v = Wind velocity (m/s)
η_T = Wind turbine efficiency
η_G = Generator efficiency

The equation shows the velocity cubed (v^3), the rotor sweep area, the air density and the turbine and generator efficiencies, hence, it is important to contemplate the turbine size to catch most out of the air mass, the installation place and the wind speed conditions [2].

A wind turbine must be built under specific requirements according the purpose and usage. In this report, the objective is to produce a residential electricity supply, which is 1500 kW/per year on average. Using the power output equation and the environment conditions, it is possible to make an analytical calculation and determine the right rotor dimensions.

2. Analytical calculation

According to Mexico City's air density, d = 0.93 kg/m^3 and the turbine and generator efficiencies which are about 0.35 and 0.9 respectably (the maximum efficiency a wind turbine could reach is 59.9%), the power output at 5 m/s produced by a 3.4 m^2 rotor is given by equation 1:

$$P = \frac{\frac{1}{2}(0.93\,\mathrm{kg/m^3})(3.4\,\mathrm{m^2})(5\,\mathrm{m/s})^3(0.35)(0.9)}{1000}$$
$$= 0.0623\,\mathrm{kW/h}$$

There are 8760 hours in the year, so the 0.0623 kW/h are equivalent to 545.33 kW/h per year.

Tab. 1 shows the power output at different velocities produced by 35% efficiencies and 3.4 m^2 wind turbine on ideal conditions.

Tab. 1 shows the average velocity at which it reaches the required power, and the velocity is approximately 7 m/s for this kind and size of wind turbine. However, the turbine had to be resized because of the laboratory conditions, in the scale ratio of 1:3. To determinate the model velocities range it was necessary a power relation between the model and prototype.

Table 1. 3.4 m^2 wind turbine power output.

Velocity m/s	Power output kW/h	Power output kW/h per year
3	0.0134	117.79
5	0.0623	545.33
7	0.1708	1496.38
10	0.4980	4362.61
15	1.6808	14723.81
20	3.9841	34900.89

The power relation between model and prototype is given by:

$$\frac{P_p = \frac{1}{2}\rho A_p {v_p}^3}{P_m = \frac{1}{2}\rho A_m v_m^3}$$

In which the power output and the air density are the same for both, 1500 kW/h and 0.93 kg/m^3 respectively as well as the efficiencies, then the equation is:

$$A_m {v_m}^3 = A_p {v_p}^3$$
$$v_m = \sqrt[3]{\frac{A_p {v_p}^3}{A_m}} = \sqrt[3]{\frac{A_p}{A_m}}(v_p) \tag{2}$$

With the equation 2, the velocity at which the model has to be tasted for each prototype can be determined. For example, Tab. 1 shows that the prototype needs an average velocity approximately 7 m/s to reach 0.1708kW/h equivalent to 1496.38 kW/h per year. Therefore the model velocity for a 1 m^2 turbine can be calculated by:

$$v_m = \sqrt[3]{3.4\,\mathrm{m^2}/1\,\mathrm{m^2}}(7\,\mathrm{m/s}) = 10.5258\,\mathrm{m/s}$$

That means, the required velocity to reach the 3.4 m^2 wind turbine power output at 7 m/s in the 1 m^2 wind turbine is 10.5258 m/s, and this can be proved by replacing the model velocity and the area in equation 1.

$$P = \frac{\frac{1}{2}(0.93\,\mathrm{kg/m^3})(1\,\mathrm{m^2})(10.5258\,\mathrm{m/s})^3(0.35)(0.9)}{1000}$$
$$= 0.1708\,\mathrm{kW/h}$$

This power output is the same shown on the Tab. 1 for the 3.4 m^2 wind turbine at 7 m/s, which is equivalent to 1496.38 kW/h per year.

3. Blade design

The design of blade was executed into a 3D sketch (Fig. 1-a). First, the sketch was divided into five parts, each part have a different twist angle from top to the base reaching 180°. The blade structure is based on semicircles which give the diameter in each section (Fig. 1-b); such diameters change as are approximate to blade center. The structure is symmetrical from the center to the ends but with opposite direction. Once the structure was established, the blade surface was created by the lofted surface tool using splines to delineate the blade border (Fig. 1-c); the base has 0.4 m diameter and with 1 m height. The top and the base are 1 diameter separate each

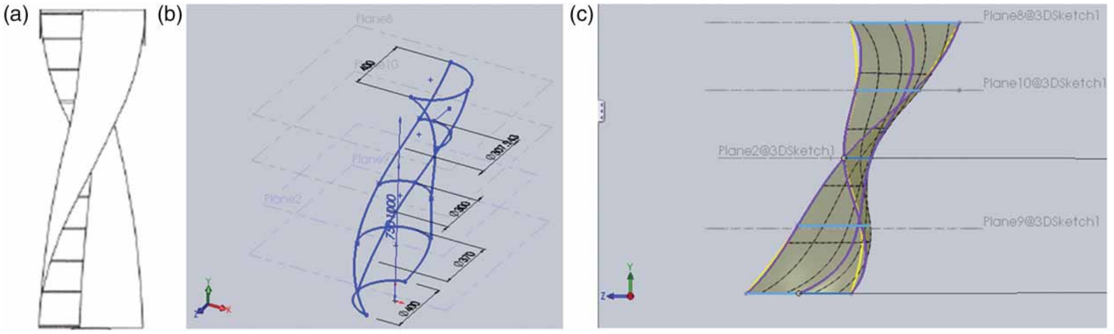

Figure 1. Blade design on 3D sketch: (a) Helical rotor outline, (b) 3D sketch for the blade design, (c) Aluminum blade surface.

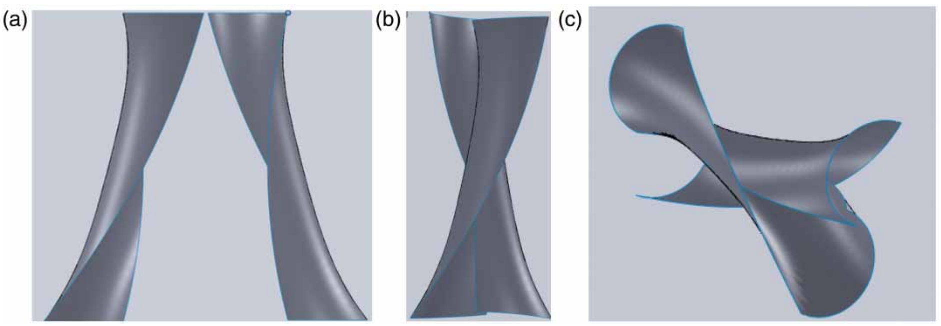

Figure 2. Blades assembly on CAD: (a) Twist blades, (b) Blades assembly, (c) Second view blades assembly.

other respect the axis. The surface was elaborated with aluminum, a material that is light-weight, strong and easy work with.

The turbine has two identical twist blades with a 180° torsion (Fig. 2-a). Both blades are placed facing away from each other to have 360° of sweep area (Fig. 2-b) to then be assembled on a 1.5 m steel shaft. The blades assemble was carried out by holding the ends of each blade on the shaft, base and top of each blade with the same extremes of the other but in opposite directions (Fig. 2-c) [4],[5].

4. Manufacture

Based on the 3D sketches, a plaster mold for the blades was developed (Fig. 3-a). The mold was used to cut sheets and make the blades. The original material considered was aluminum but the final blades were manufactured on galvanized steel gauge 18 (Fig. 3-b) to reduce costs.

When cutting the blades, both sheets were rolled to make twisting on the shaft easier. Then the blades were set on the shaft (Fig. 4-a) which has two arms where the extreme of each blade were introduced and welded (Fig 4-b). The other side of each blade was turned around the shaft and riveted on it giving it to the rotor the final twist (Fig. 4-c)

Finally, the rotor was set on a tapered rolling bearing to reduce friction and bear high axial loads. The base was a 30 kg steel plaque in which the rotor was welded on a PTR structure to increase stability and reduce vibration.

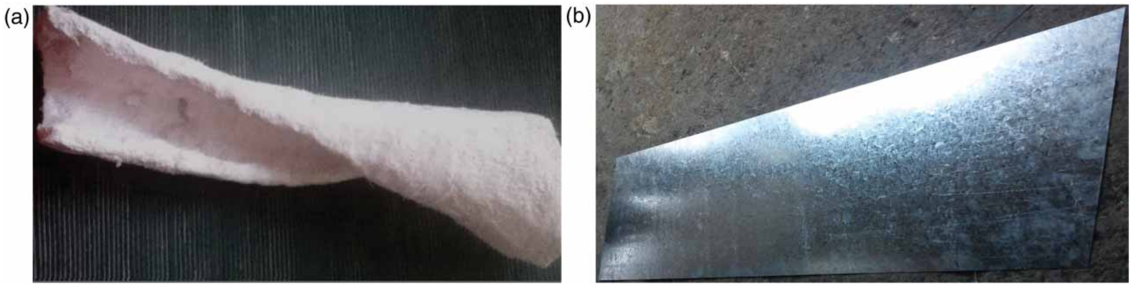

Figure 3. (a) Plaster mold, (b) Galvanized steel sheet.

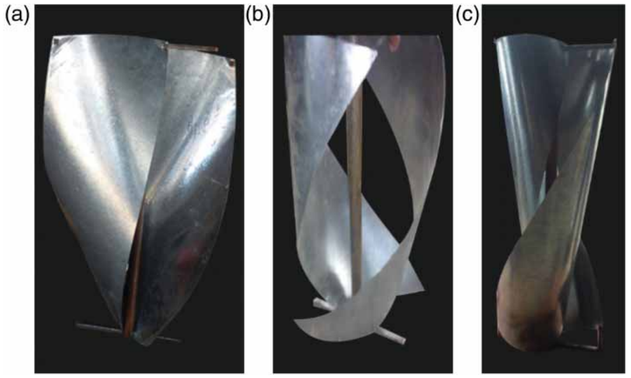

Figure 4. Rotor construction: (a) First roll over the sheets and set on the shaft, (b) Weld of the blades on the shaft, (c) Final roll and rivet.

5. Experimentation and results

The experimentation was realized in two centrifugal fans using a hot wire anemometer for the velocity flow measure. The fans were installed one over the other in vertical position to cover all the rotor sweep area (Fig 5). To calculate the velocities profile, the air flow was measured along the pipeline diameter to assess the flow behavior and establish the rotor position [3].

The measurements of velocity test range from 5 m/s to 14 m/s and the turbine power curve was determined by obtaining the torque produced by the rotor in each velocity. The results shown at the Tab. 2 are for the 1 m^2 turbine. The 1500 kW/h per year are reached at the velocity of 10.2 m/s approximately, equivalent to 6.79 m/s in the 3.4 m^2 turbine. These results are similar at the analytical data shown before.

Figure 5. Experimental Tests: Rotor installation on the tests zone.

Table 2. Experimental results.

Turbine rps.	Vel. m/s	Torque Force kg.F	Power output W	Annual power output kW/h
1.7	5.1	0.4	0.227	119.56
1.9	5.5	0.5	0.284	149.45
2.1	6.2	0.8	0.455	239.11
2.4	7	1.2	0.682	358.67
2.7	7.4	1.5	0.853	448.34
3	7.7	1.7	0.967	508.11
3.5	8.3	2.1	1.194	627.67
3.9	9	3	1.706	896.67
4.2	9.5	4	2.275	1195.56
4.6	10.2	5	2.843	1494.46
4.7	10.35	5.3	3.014	1584.12
5.2	11.7	7.5	4.265	2241.68
5.7	12	8.3	4.720	2480.80
6.1	13.2	10	5.687	2988.91
6.4	14	12	6.824	3586.69
6.6	15	13	7.39	3885.58

6. Conclusions

A helical vertical axis wind turbine was built with the purpose of covering the electricity supply for a household with an average consumption of approximately 1500 kW/h per year. The turbine was subjected under many tests to confirm its performance and operation ranges. After analyzing and comparing the results with the analytical data, it was determined that the helical wind turbine could be a viable alternative option for its use to generate cost-competitive energy. Wind power is a clean and inexhaustible source of renewable energy, which has experienced dramatic growth in the last decade. Considering the featured benefits, such as the construction and maintenance costs, turbine size and operation requirements, this rotor mechanism could be a scalable solution, which has a significant expansion potential to address the current renewable energy demands.

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