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Design and construction of a wind turbine with an approach to urban beautification Elements

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Abstract

One of the most important sources of energy that has been attracting the attention of many countries in the world is wind energy, which is very clean, cheap and permanent. In this article, a statistical analysis of wind speed data in Chabahar port in the south of Sistan and Baluchestan province has been conducted. Based on the data, the necessary design and simulation was carried out for the construction of a vertical axis wind turbine. Small-scale samples were made using 3D printers and patent and industrial design certificates were obtained. Finally, a feasibility study for the construction of a 1000-meter-long street lighting network, including lighting poles with hybrid wind-solar systems using LED lights, was submitted to the Chabahar Free Zone Organization. In this project, the system is built in such a way that, while preserving the beautification element, it is able to provide lighting for the entire route. The results show that by installing vertical axis wind turbines, it is possible to reduce fossil fuels by using renewable energy up to zero.

Key Words: Wind turbine, wind, density, element, torque

1. Introduction

Given that in the third millennium there is a close interaction between the city and the citizen, it is clearly clear that beautification projects must be defined in order to expand this relationship. Therefore, the vision of city managers is to achieve a creative, nurturing, promising and beautiful city. A city with economic and cultural prosperity where residents and travelers enjoy being in it and use every opportunity to connect with the city. Today, in developed countries, the goal of beautification is to provide an environment where everyone feels calm. The design, construction and installation of urban beautification elements that combine architecture and attention to green energy management are one of the main goals of the urban beautification development project. The use of more and more renewable and non-polluting energy is increasing. Among all natural forces, the ease and continuity of wind power in some areas, along with the problem of energy waste, has led to the issue of using energy generators and coordinating them with the urban environment. The installation of wind turbines in public spaces and combining them with beautification elements is an example of these trends. However, horizontal axis turbines in urban environments, due to the presence of right-angled edges of buildings and the creation of air

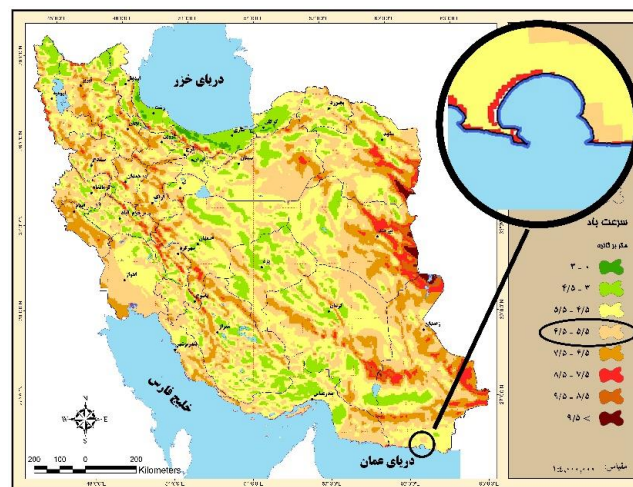
turbulence around them, and the environmental impacts caused by the rotation of blades, have not had an acceptable evaluation. In addition, the advantages of vertical axis turbines are summarized as follows:

- Vertical axis turbines have a strong structure that prevents control problems.
- These turbines can receive wind energy in any direction.
- Vertical axis turbines are quiet and silent.
- These turbines, due to their narrow structure, have a high ability to connect to the local network.

Vertical axis turbines can provide the required energy from urban flows. Therefore, the role of designers to create vertical axis turbines, on the one hand, with a focus on the flow entering the turbines, wind speed and the important issue of the impact of turbines on the urban landscape, has been one of the main challenges of engineers in recent years. The efforts that have been made from idea to action by knowledge-based companies, along with a developmental vision for the design and construction of the first 300-watt small-scale wind turbines based on urban beautification elements and the production of clean energy with an integrated design approach and inspired by the necessary criteria Integration of architectural and energy engineering to provide street lighting in a pilot project is described below.

Based on the Iranian wind atlas [1], the general area of Chabahar at an altitude of 10 meters has an average wind speed of between 5.5 and 6.5 meters per second.

On the other hand, with an increase in wind speed, the lift force in this type of structure will also increase, and we can expect a higher rotational speed. The Lift type is a suitable option for achieving higher rotation, but for high torque operation, the drag type is preferred. In other words, drag type turbines can operate with a wind speed that Lift type turbines have not yet started rotating in.



The findings of conducted research have shown that the stations of Siri, Zirin-e-Obatoo, Torbat-e-Jam, Bandar Chabahar, Abu Musa Island, Tabriz, Zahedan, Nojeh Hamedan, Sardasht, and Kermanouj fall into a statistical classification with an average annual wind speed of 6 to 10 knots (equivalent to 6.3 to 8 meters per second). A ten-year statistical analysis has shown that Bandar Chabahar has wind speeds exceeding 10 knots for more than 50% of the time. Additionally, local station data has recorded the maximum wind speed during the spring and summer seasons.

Therefore, in terms of wind energy potential at the national level with values ranging from 200 to 500 joules per square meter, the Chabahar station is located in an area where conditions for wind turbine deployment are available on many days of the year, making the operation of these turbines economically feasible. However, the lack of cost-effectiveness in installing conventional wind power plants with a capacity of over 50 kilowatts has justified the substitution of vertical axis turbines with lower capacities in these climatic regions.

2. Basics of Turbine Design

Vertical axis turbines are divided into two categories based on the type of blade operation: the first category is considered to be Lift Type, which follows Bernoulli's principle and creates lift force perpendicular to the wind angle of attack. The second category is considered to be Drag Type, which directly captures its energy from the wind's kinetic energy.[2] Among the types of vertical axis turbines, the Lift Type blades have gained more popularity today due to their high efficiency coefficient, leading to widespread use of this type of blade in wind turbine manufacturing (Figure 1).

$$C_l = \frac{2l}{A\rho v^2}$$

In which C_l is the lift coefficient, A is the blade area in square meters, ρ is the density in kg/m^3 , v is the velocity in m/s , and these variables are the parameters of the equation.



Figure 1: Lift force and its effect on the motion of the blades

However, the excess lift force generated by this type of blade must be completely dissipated by the structure, leading to fatigue and wear over time and making the operation of this type of turbine dependent on very complex parameters. This has made the use of vertical axis turbines in large dimensions challenging, requiring fundamental changes. As the wind speed increases, the lift force in this type of structure will also increase, allowing us to expect higher rotation speeds (Figure 2).

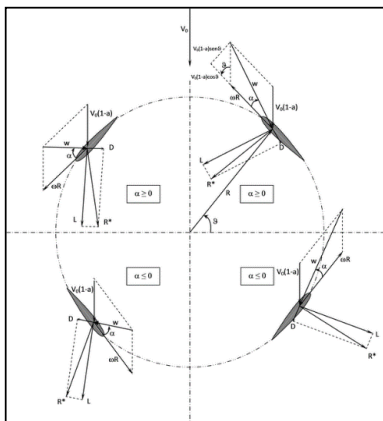
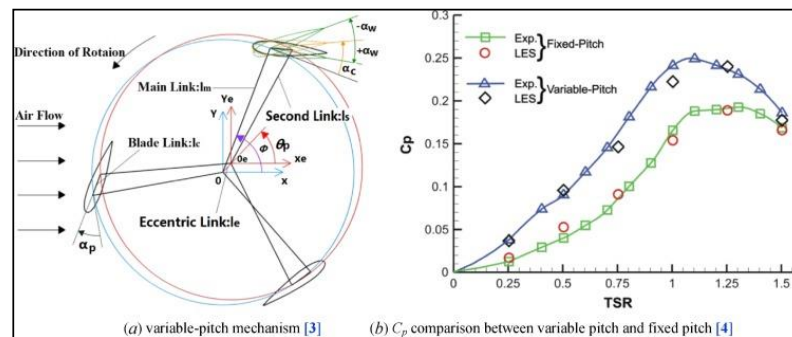


Figure 2: Rotation of turbine blades due to the lift force performance

On the other hand, with an increase in wind speed, the lift force in this type of structure will also increase, allowing us to expect higher rotation speeds. The Lift Type is a suitable option for achieving higher rotation speeds, while the Drag

Type excels in high torque applications. In other words, Drag Type turbines can enter the energy production cycle at a wind speed where Lift Type turbines have not yet begun to rotate. These types of turbines take the necessary torque to overcome the inertia or rotational stiffness of their own from Drag Type blades and then increase the rotation speed through Lift Type blades. One advantage of the vertical axis turbine over the horizontal axis turbine is its ability to be affected by turbulent wind flows in various directions without changing the direction of the structure, reducing part of the structural cost and facilitating its use (in the production and installation process) compared to the horizontal axis turbine.

In the curve (1), the input torque of a vertical axis turbine with three helical blades is shown over a 360-degree rotation cycle. As you can see, the torque in this type of turbine is not linear and increases gradually, regardless of the type of turbine (like the horizontal axis turbine).



Curve (1): 360-degree rotation of a three-bladed helical turbine due to the application of lift torque

Based on analysis and studies, the drag type is the best choice for designing, allowing us to use composite or metal sheets without the need for complex curved forms in production. This reduces the weight of the structure to a great extent and does not create any production complexity. The way these sheets interact with the structure is very important, and the smarter it is, the higher the efficiency will be. Therefore, designs in this field are very different, and each group designs according to its own needs, expectations, and production capacity. Therefore, maximizing the kinetic energy of wind movement is particularly important in these designs. [3]

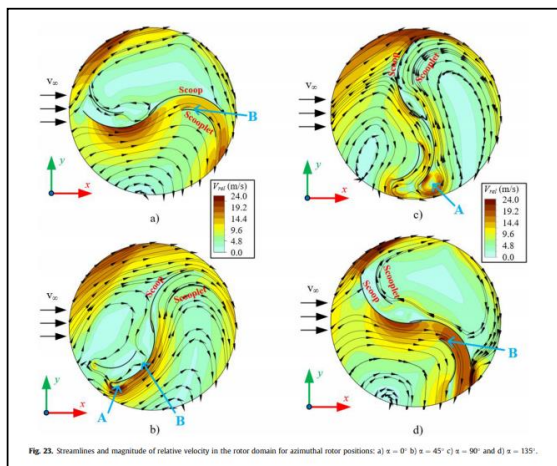


Fig. 23. Streamlines and magnitude of relative velocity in the rotor domain for azimuthal rotor positions: a) $x = 0^\circ$ b) $x = 45^\circ$ c) $x = 90^\circ$ and d) $x = 135^\circ$.

The common form for vertical axis turbines of the drag type is a helix shape with two flat blades that not only absorb wind kinetic energy but also direct it and receive torque in the return path. This secondary torque, shown in Figure (3), is created by an overlap between semi-circles, which is logically determined for it. However, if the number of blades exceeds two, the interference between the blades does not allow the flow to pass and this torque exchange.

Figure 3: Circulation flows around the helical blade

As the number of blades increases, the rotational stiffness of the structure and the efficiency of the structure increase simultaneously, but not linearly. When the number of blades exceeds 6, the efficiency decreases, and the wind flow bypasses the structure. On the other hand, as the structure occupies a larger surface area, a destructive torque in the direction of overturning is introduced into the structure, which, if it does not lead to the uprooting of the structure in stormy conditions, will require bearing replacement in a short time. To increase the stability of the structure as well as the performance of the rolling elements, we use a wheel instead of various bearings at the center of the structure to withstand these stresses, and we design accordingly.

3. design with an approach to urban beautification Element

From our approach to the design of vertical-axis turbines, the beauty of this turbine is for use in urban spaces and as an urban element. This turbine has a completely plant-based design inspired by flowers and is entirely producible due to its flexibility. Therefore, the flower design was used for the process of analyzing wind fronts and flows. Using Solid Works software in this analysis, the base wind flow rate was considered to be 10 meters per second. According to the analysis shown in Figure (4), this turbine was designed and analyzed based on clockwise rotation, and as can be seen, the maximum wind speed reduction occurred behind the blade in line with the vortex, which has a speed of less than 1 meter per second, causing this propeller to rotate in this direction. After each analysis, the angles and designs of the blades were improved, and we reached a more beautiful and optimal schematic.

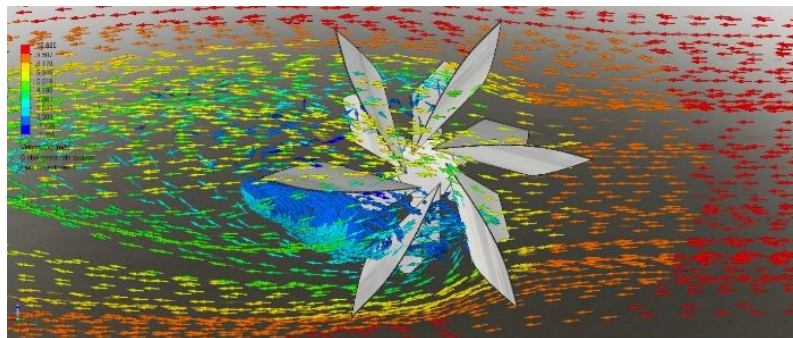


Figure 4: Wind flow analysis in turbines with 6 helical blades

Blades that are aligned with the wind flow direct the flow towards the opposite direction of their movement. Although this creates rotational force, the blade that is positioned in the opposite direction receives the wake of this flow, creating a negative torque that causes the turbine to lock and not move. To solve this problem, the turbine needs to rotate at about 60 revolutions per minute so that the torque obtained each turn can overcome the braking force and cause it to rotate. As this is not possible, and we expect the turbine to start rotating with the wind force from the beginning, we have modified the design accordingly.

According to the optimization shown in Figure (5), the final design of the vertical-axis turbine with five blades inspired by a flower has been achieved. This turbine has five energy discharge

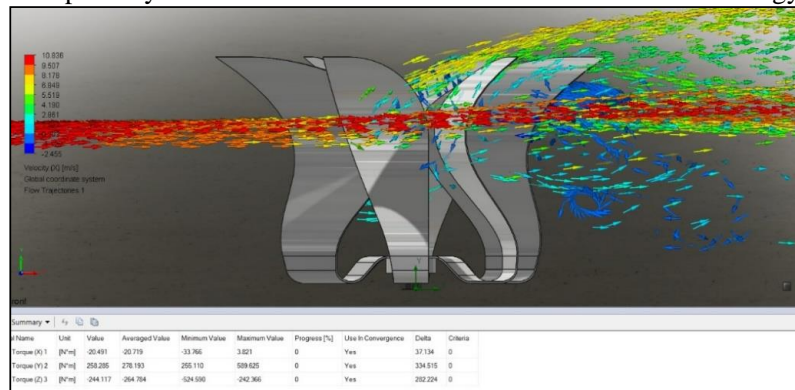


Figure 5: Wind flow analysis after implementing a flower-shaped design as an aesthetic element

windows instead of two, unlike conventional turbines. Based on simulations, the wind flow with a speed of 3 meters per second gets trapped in the negative space behind the blade, then after discharging its kinetic energy, it passes through the central space and enters the blade area in the opposite direction, then it is directed by the blade and creates positive torque.

4. Kinematic equations and formulas of motion

To design a suitable turbine, it is necessary to consider the principles and relationships governing the Gorlov helical turbine. As seen in Figure (6), Gorlov turbines provide the possibility of obtaining more energy up to 200 watts compared to other types of turbines. To choose the best type of turbine, the performance of the blades must be considered by modifying their aerodynamic shape. Therefore, the Darrieus turbine was redesigned by changing the shape of the blades and optimizing the cross-sectional area to convert the kinetic energy into electrical energy.[4]

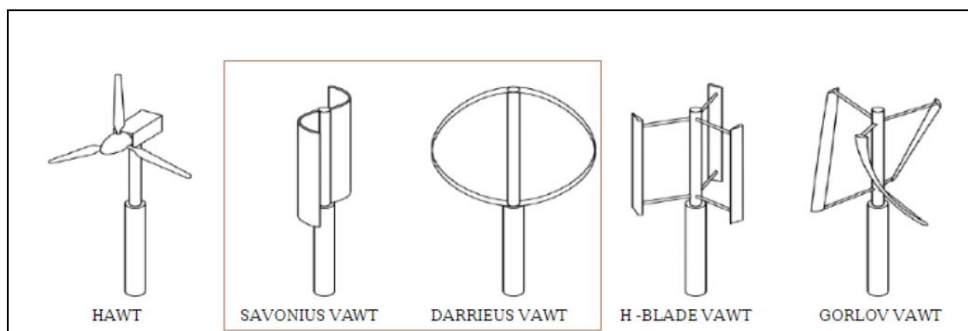


Figure 6: Classification of horizontal-axis and vertical-axis wind turbines

Based on the studies conducted, the degree of twist and the rectangular shape of the blades are essential factors.

$$P_{wind} = 1/2 \times C_p \times A \times V^3 \quad (2)$$

In which C_p is the power coefficient, A is the blade area, and V is the wind speed

In this case, we have $S = 2R$, where S is the cross-sectional area of the sweeping region of the blade in square meters. The next factor is the wind power, which is a function of the cube of the air velocity, according to the formula where C_p is the power coefficient, A is the blade area, and V is the wind speed. Such power can be obtained from the wind by considering the power coefficient (C_p). The maximum value of this coefficient, known as the Betz limit, is 55%, meaning that in the best case, only 55% of the mechanical power obtained from the turbine's operation can be converted into electrical energy.[5]

According to the statistical data of the Chabahar region, and considering the air density and average wind speed at a height of 10 meters, the equations governing the energy extraction from the turbine are defined as follows:

$$\rho = 1.13 \text{ kg/m}^3$$

air density

$$C_p = 0.55$$

albert Betz limitation

$$\gamma = \frac{0.7}{2} = 0.35$$

$$v = 8 \text{ m/s}$$

Relative velocity of the flow)3)

$$\lambda_{av} = \frac{(2.5+2)}{2} = 2.25$$

The average wind speed in Chabahar at a height of 10 meters

(4)

$$\omega = \frac{(2.25 \times 8)}{0.35} = 51.4 \text{ rad/s}$$

radial speed (5)

$$A = 1.5 \times 0.7 = 1.05 \text{ m}^2 = 5.25 \text{ m}^2 \text{ for 5 blade}$$

blades area (6)

$$T = \frac{(\frac{1}{2} \times 0.55) \times 1.13 \times 5.25 \times 8^3}{51.4} = 16.25 \text{ Nm}$$

Calculating the turbine torque force)7)

$$P_{flow} = \frac{1}{2} \times 1.13 \times 5.25 \times 8^3 = 1518.7 \text{ watt}$$

Turbine power) 8)

$$P_{turbine} = 1518.7 \times 0.2 = 303.7 \text{ watt}$$

the electric power extracted by the turbine, which is 20% according to the Betz limit. 9)

As a result, it is possible to extract electrical energy in the worst-case scenario of 300 watts and in the best-case scenario of more than 800 watts in the Chabahar region and other coastal areas in southern Iran.

At the same time, fundamental principles such as wheels and ease of construction are emphasized, and all blades can be produced by laser-cut curved sheets. The optimized design has performed successfully in all parameters and produces high torque (without negative force). According to the analysis, the wind flow at a speed of 3 meters per second is trapped in the negative space of the blade and, after discharging kinetic energy, passes through the middle

space and enters the blade space in the opposite direction, then finds its direction by the same blade and creates positive torque.

With an increase in the wind absorption area of the turbine, more wind power can be harnessed. This process is repeated every sixty degrees, continuing the torque-generating cycle. According to the analysis performed using Solid works software, the resulting torque from this flow (around the Y axis) will be an average of 16.25 Newton meters. The structure's mass is estimated to be around 100 kilograms if produced with composite materials. In general, it is not possible to estimate an accurate figure for this complex structure's rigidity, but the acceleration that the structure will start to move due to its motion can be estimated, which is equal to 16.25 divided by the mass of the structure (approximately 100 kilograms).

5. Blade Design finalization

This design has many advantages according to the analysis. One of these advantages compared to the previous design is that the wind flow passing through the back of the cap perpendicular to the flow reduces the pressure behind the cap and generates torque in the positive direction (Bernoulli's principle leading to lift). On the opposite side, the same cap shape, by receiving the output flows, generates positive torque. This indented shape traps the flow on one side and receives all its kinetic energy, and on the other side, it allows the flow to pass through its spherical back and creates minimal interference. Additionally, this structure can be very tall, depending on the production team's limitations, to access higher wind currents.

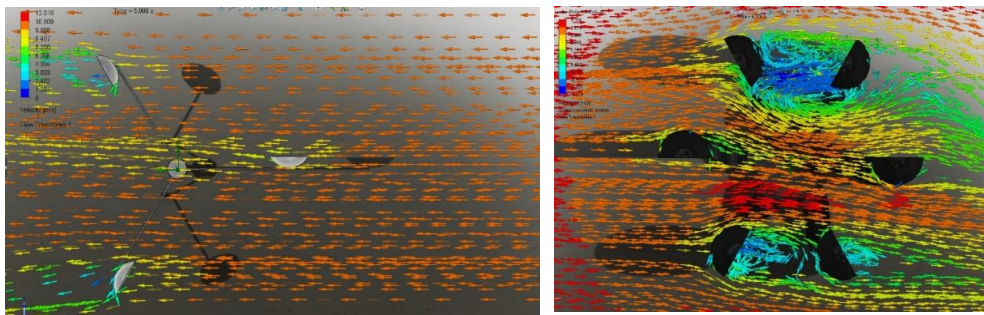


Figure 7: Wind attack analysis with 6 cups that causes the creation of negative torque

6. Hybrid system design

Figure (7) shows the designed structure, which includes a 12-meter galvanized steel base. This structure should not only have the properties of a lighting base and maintain energy production facilities but also be aesthetically pleasing.

Figure (8) shows a lighting base with the relevant details. As can be seen, a 300-watt wind turbine made of lightweight composite material is installed on the top section. The turbine is connected at the end to a shaft, a brake system, and also to rolling bearings, and is coupled to a permanent magnet iron generator that acts as a power generator and allows us to eliminate the need for a gearbox. Alongside it, a wind sensor has been installed which, in addition to

monitoring wind speed, also performs wind direction sensing and in case of heavy winds, the automatic alert system will activate, including locking and breaking the turbine. Two 150-watt solar panels are installed on the lower part, which perform hybrid energy production for the structure. After that, double-sided LED lighting fixtures are installed, which are powered by direct current voltage of 24 volts and can absorb a total power of 280 watts. At the end, there is a direct current generator system that converts mechanical power to electrical power and charges the acid battery set installed at the end of the structure with the help of an AC charger. The intelligent control system, GPRS communication module, and other equipment are installed in this section.



Figure 8: street lighting structure

Figure 9: pilot project site



7. Pilot project

For the implementation of a pilot project, the stretch between South Gate to the

entrance of the Bandar-e Rigi Free Zone building, with a length of 1000 meters, has been selected on Shahid Rigi Boulevard. The project includes the following specifications:

- A) Design, construction, installation, and commissioning of 38 hybrid 12-meter lighting poles
- B) Installation of 88 140-watt LED lights with direct current
- C) Installation of 92 150-watt solar panels
- D) Installation of 38 300-watt wind turbines
- E) Installation of 6 special light decoration wind turbines for the south and north gates
- F) Design, construction, and installation of two wind turbines with special urban elements for two square.
- G) Control panel and related systems

In figure (9), the location of the project is shown.

8. Coats evaluation

Based on the designed equipment for the implementation of the pilot project, the cost of about 150.000 USD has been estimated. also, considering with the zeroing of grid electricity use, we have:

- Annual energy savings: 87 megawatt-hours.
- Annual energy savings cost: 2000 USD.
- The value of the symbol of urban beautification: total price 60 million USD.
- Return on investment (only for the energy production section): 4 years.

9. Conclusion

In this article, in accordance with the patent and industrial registration certificate, the possibility of piloting a project on the southern coasts of the country (Bandar-e Chabahar) has been investigated and attempted to demonstrate that by zeroing the use of electrical energy and reducing the annual consumption of 87 megawatt-hours of lighting for a kilometer of implementation of hybrid street lighting systems, an annual reduction of 43 tons of pollutants such as carbon dioxide emissions can be achieved per kilometer of street lighting network. Additionally, considering the lack of lighting on many of the country's highways and the significant human and financial losses caused by the lack of lighting, especially in narrow and steep mountainous passages, the implementation of this system can be highly effective and can create employment opportunities through attracting investors and collecting fees. For example, in the case of the Rahal project, the inspection of the 200-kilometer Bandar Abbas - Hajiabad freeway can not only provide lighting and driving safety but also save 17,500 megawatt-hours of electricity annually and prevent the emission of 9 million tons of pollutants, resulting in savings of about 300.000 USD in electricity costs.

10. References

1. <http://energysaving.ir/Fa/Content91.html>
 2. M. A. Rosen, J. O. Ajedegba and G. F. Naterer, "Predicting Vertical Axis Wind Turbine Behaviour: Effects of Blade Configuration on Flow Distribution and Power Output," Nova Science Publishers, Inc., Ontario, 2010.
 3. Y.-b. Liang, L.-x. Zhang, E.-x. Li, X.-h. Liu and Y. Yang, "Design Considerations of Rotor Configuration for Straight-Bladed Vertical Axis Wind Turbines," *Advances in Mechanical Engineering*, 2014.
 4. A. M. Gorlov, Unidirectional helical reaction turbine operable under reversible fluid flow for power systems, United States Patent 5,451,137, Sept. 19, 1995
- L. Deisadze, D. Digeser, C. Dunn and D. Shoikat, "Vertical Axis Wind Turbine Evaluation and Design," WORCESTER POLYTECHNIC INSTITUTE, Worcester, 2013.