RESEARCH REGARDING THE DEVELOPMENT OF A SMALL WIND TURBINE

BURLACU V. Andreea-Elena[1], GHEORGHE M. Antonel[1], DOICIN Cristian Vasile[2]
[1]Faculty: Industrial Engineering and Robotics, Specialization: Economic engineering and business management, Year of study: I, Master
e-mail: antonel.gheorghe@stud.fiir.upb.ro
[2]Faculty of Industrial Engineering and Robotics, Manufacturing Engineering Department, University POLITEHNICA of Bucharest

ABSTRACT: In the past couple of years, the transition to green energy has become one of the goals of the European Union, with the aim of ensuring an improvement in the people's quality of life, while considering the need to protect the environment. With this in mind, innovation in the past couple of years had strived to improve and bring forth solution which are friendly to the environment, and furthermore, even reinvent what we perceive as power sources, in order to use accessible resources without creating more waste. In this context, this paper studies an experimental model of a small wind turbine powered by wind currents generated from intense traffic on highways. The goal of the proposed prototype is a green alternative to energy production that can help light posts along the road or provide electricity for potential charging stations. The proposed methodology is the result of a combination of the study of the need for such a solution in the current market context and the design and implementation of the proposed solution.

KEYWORDS: Vertical Axis Wind Turbine, Wind energy, Green energy, Renewable energy, Alternative source of energy.

1. Introduction

Wind turbines can generate energy that can be fed into grid systems or used to power homes and businesses. Most of the wind systems that are used to generate power are large wind turbines that average over 30 meters in height and are generally installed in fields, outside cities and offshore, far from shore.

Small vertical axis wind turbines are wind power generators that are small compared to wind power generators used on an industrial scale. They are designed to convert the kinetic energy of the wind into electrical energy. They are usually composed of a rotor, a gearbox, an electric generator and a support structure. The rotor is the part that captures the wind energy and is made up of several blades (usually between 2 and 6). These blades are designed to rotate around an axis in the direction of the wind. When the wind hits the blades, the rotor spins and the kinetic energy of the wind is converted into mechanical energy via the gearbox. The gearbox is located between the rotor and the generator and has the role of increasing the rotation speed of the rotor and transmitting mechanical energy to the electric generator. The generator then transforms mechanical energy into electrical energy, which is then transferred to consumers or the public grid.

Small vertical axis wind turbines are designed to operate at lower wind speeds because the wind is less constant and weaker in urban and rural areas than in open sea or plain areas. Therefore, the rotor blades are smaller and lighter than those of large wind turbines, and the maximum rotation speed is lower. They are also designed to be more compact and easier to install and maintain. They are typically used to provide electricity in isolated areas or to power small consumers such as homes and small businesses and street lighting. Upon a closer study of the differences between industrial wind turbines and small ones, we can note some of the advantages of using the latter for this work. At the moment, there are discussions regarding the negative effect of large turbines both on the environment due to the noise produced and the destruction of the habitat for animals and birds, and on the security of the airspace due to the disruption of radars. In addition, this type of wind system required a significant financial effort due to installation, maintenance and monitoring during the operating cycle, in addition to the logistical effort regarding the network and transport infrastructure.

In comparison, small vertical axis wind turbines are more environmentally friendly, generating less noise, and by nature of small size design, no longer a factor affecting the life of surrounding animals or air traffic. Also, another aspect that supports the premise of this work refers to the possibility of placing the turbines closer to the grids or current consumers, which would require lower infrastructure costs and would also represent an advantage for transport and maintenance costs.

2. Current stage of research

The vertical axis wind turbine industry has grown in popularity in recent years, as it offers significant advantages over traditional large-scale horizontal axis turbines. While horizontal axis turbines are the most widespread in the market, vertical axis turbines have several advantages. Historically, they have been relegated to fulfilling a small niche market in commercially available wind turbines due to their design. Current projects lag their horizontal axis wind turbine counterparts in terms of efficiency, measured by their power coefficient. However, new research suggests that these types of turbines may be more suitable for wind farm installations than previously thought.

One of the major advantages of these turbines is that they can be installed in tighter spaces and can be positioned closer to the ground. This makes them ideal for use in urban environments where space is limited, and wind conditions are often weaker. While they do not achieve the performance of horizontal axis turbines at greater heights, they are ideal for use in rural communities, for powering residential and small buildings, and even for road infrastructure and street lighting projects. While not yet as widespread as other methods of generating electricity, vertical axis turbines have high potential to provide a sustainable and energy-efficient alternative for a wide range of applications.

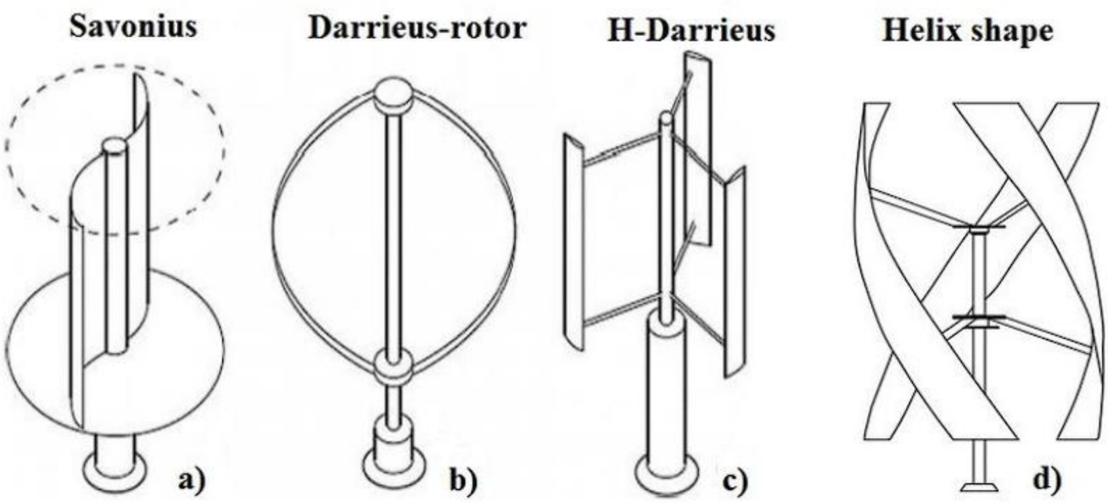
Vertical axis wind turbines (VAWTs) are typically small wind turbines characterized by a rotation axis perpendicular to the ground. As a result, VAWTs can operate independently of the wind direction, which is a major advantage for applications where the wind direction can change rapidly. The two primary models are derived from either Darrieus or Savonius rotors.

Table 1. Vertical axis wind turbines [2]

Manufacturer	Model	Area (m^2)	Power (kW)	Rated speed (m/s)	Cut-in speed (m/s)	Cut-out speed (m/s)	Noise
WePower,	Falcon 1.2	3.5	1.2	13.0	2.7	49.6	32
Quietrevolution	qr5	13.6	3.3	11.0	4.5	19.0	58.0
Turby		4.9	2.5	14.0	4.0	14.0	N/A
Urban Green Energy	Eddy	2.1	0.65	12.0	3.5	32.0	36.0
Windspire Energy	Windspire	7.4	1.2	10.7	3.8	N/A	6.0
Windside Oy	WS-4A	4.0	0.24	18.0	1.9	N/A	N/A
Urban Green Energy	UGE-4K	12.5	4.0	12.0	3.5	25.0	38.0

The Darrieus design has the shape of an eggbeater and uses long airfoil-shaped blades to extract energy as the wind strikes the blades perpendicularly. There are several variants on the Darrieus rotor, including some with straight blades or more advanced models including those based on silence. In ideal low-turbulence wind environments, Darrieus turbines tend to be less efficient than horizontal axis turbines; but in high turbulence conditions, such as wind with directional fluctuations in an urban setting, Darrieus machines can perform better and produce more energy than horizontal axis machines.

The Savonius design features a turbine whose blades have an "S" shape in cross section. Because of their curvature, the concave surface has greater resistance than the convex surface, forcing the rotor to



spin when the cups are exposed to wind.

Compared to horizontal axis turbines (HAWTs) and the Darrieus design, Savonius models rotate slowly but with high torque. Although they have low cut-in speeds, resistance-based turbines are generally not considered good for electricity generation. Additionally, Savonius turbines use more material than Darrieus machines and achieve significantly lower aerodynamic efficiency.

Supporters of vertical-axis turbines identify several advantages over horizontal-axis turbines for urban applications. Firstly, they are considered preferable for rooftop applications because they can handle wind from all directions and can perform better in turbulent conditions than horizontal-axis turbines. Secondly, they tend to operate at lower rotational speeds and have fewer moving components, such as no yaw system to orient the turbine into the wind, which theoretically can reduce maintenance costs. Thirdly, due again to the lower rotational speeds, they can emit less noise, which can be a major issue for wind turbines near residential areas. Finally, vertical-axis turbines are considered more aesthetically pleasing and more capable of being integrated into the built environment as an architectural feature.

However, despite these capabilities, some analysts in the wind industry believe that this type of wind energy extraction is not a viable solution for wind energy in cities. The biggest reservations are that their relatively lower efficiency cannot yet justify the high costs of production and maintenance. Until small-scale vertical axis turbines become more cost-effective, it is unlikely that they will have a major presence as a method of generating electric power compared to solar panels, which are becoming increasingly cheaper and regulated in the European market.

3. Proposed solution

The experimental model presented in our paper aims to convert the wind and air currents produced by highway traffic and beyond into renewable energy that can be used for local road lighting and, in the future, to power charging stations for electric vehicles. Additionally, due to its design and quiet nature, they can be installed in large numbers between the median barriers of the highway. Moreover, due to their sustainability and proposed design, maintenance teams would benefit from reduced costs due to their placement on highways.

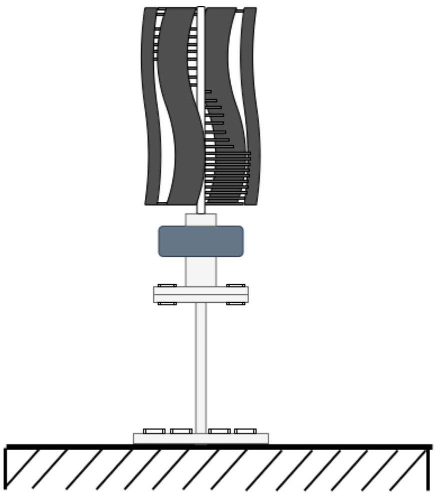


Fig. 2 Experimental model diagram

The proprietary solution represents an experimental model achieved by combining the H-Darrieus and Savonius turbine design with a spiral one in order to obtain a new, innovative product with high efficiency and benefiting from all the main features of established wind turbines. The purpose of this turbine is to generate electricity primarily based on the wind currents generated by moving vehicles on the highway, as well as the natural wind currents in those areas. Thus, the experimental model aims to be part of an array of turbines of this kind, so that the power generated by them can have multiple applications such as:

a) Powering street lighting within the highway, lighting which is currently non-existent due to the lack of a nearby electrical power source or due to complicated logistics and high implementation costs.
b) Source of energy for electric vehicle charging stations.

c) Source of energy for refueling stations for alternative fuels.

d) Transmitting excess electric current to the public grid as an ecological method of generating electricity and more; a method that generates electric energy using "polluting" traffic, thus providing a significant contribution to combating CO_2 emissions.

To determine whether such a solution is feasible and more importantly viable, the entire length of the A2 Sun Highway will be used as an experimental example. Knowing that lighting poles are installed at 50m, such vertical-axis turbines will be installed at a distance of 100m in series along the entire highway, so that for every kilometer there will be 20 lighting poles and 10 small wind turbines. Thus, the necessary number N to cover the entire highway is:

$$N = \frac{(Kilometers\ of\ highway)}{Distance\ between\ turbines} = \frac{201{,}800m}{100m} = 201.8 \quad (1)$$

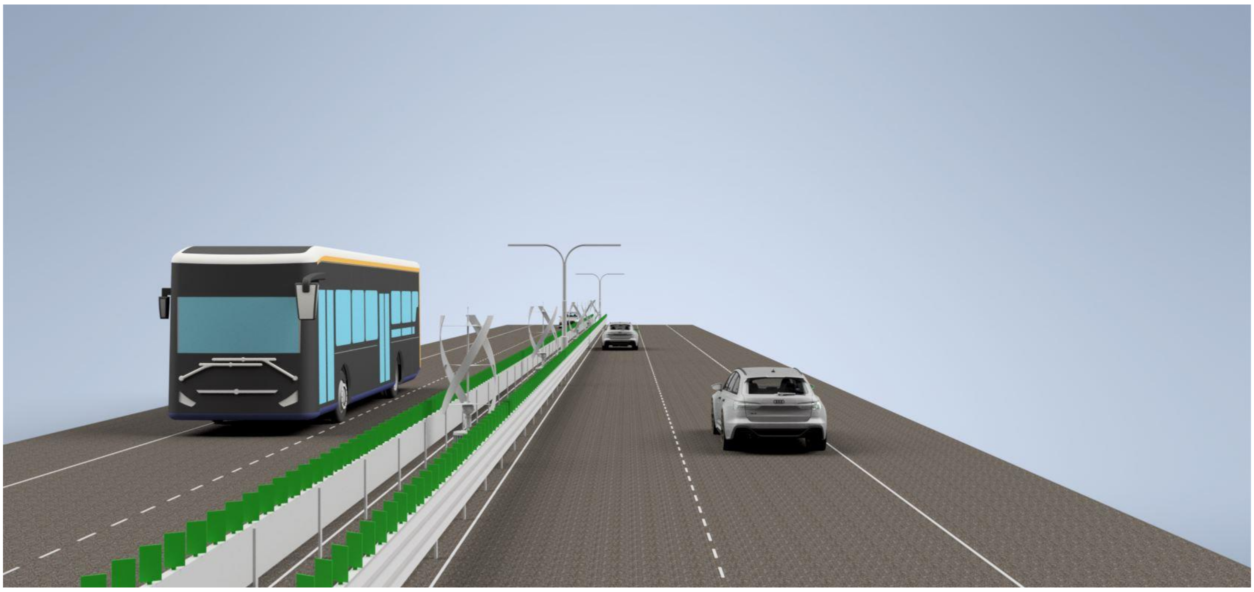


Fig. 3 Rendering of application model respecting the principle of A2 Highway

To determine the energy capacity that they will be able to produce in a normal regime, knowing that the capacities of turbines already on the market that meet the necessary characteristics range between 0.5kW and 3kW, it will be established that the power of a turbine will be 2kW under ideal conditions and 0.9-1.1kW in constant real regime.

Thus, we obtain the following data.:

$$E(kWh) = P(kW)x\,T(h) = 0.9 - 1.1kW\ x\ 1h = 0.9 - 1.1kWh \tag{2}$$

$$E(totală) = 0.9 - 1.1\ x\ 201.8 = 162.81 - 221.98\ kWh \tag{3}$$

To ensure constant operation for 24 hours of all turbines under real operating conditions, a power output between 4.6 and 5.6 megawatts can be obtained. Using Ohm's Law, we can obtain:

$$R = \frac{201800W}{220V} = 917A \tag{4}$$

To determine if this number is feasible in order to support the applications, we must also know the energy requirements for each consumer. Thus, following the market studies conducted personally, the following have been established:

Table 2. Energy consumption of potential consumers

LED street lighting pole	60– 100Wh	0.45 A
Electric vehicle charging station	3.7 – 22kWh	32A
Fuel stations	7 - 28kwh	32A

Knowing that to illuminate the entire highway, lighting poles will be installed at 50m between them, we obtain the total number needed as follows:

$$S = \frac{(Kilometers\ of\ highway)}{Distance\ between\ poles} = \frac{201.800}{50} = 4300 \tag{5}$$

To determine if the entire system can sustain street lighting under real conditions for 12 hours, the intensity of electric current produced by the turbines will be divided by the intensity of electric current required by the poles, knowing that 1 wind turbine is responsible for powering 2 street poles.

$$A = \frac{\text{Current intensity produced by 1 turbine}}{\text{current intensity consumed by 2 streetlights}} = \frac{\frac{1000W}{220V}}{0.45 * 2} = \frac{4.54}{0.9} = 5.04 \quad (6)$$

After the calculation, we can establish that the system can support street lighting, with one turbine being able to power at least 5 streetlamps at maximum capacity.

The primary goal of wind turbines will remain the priority of powering public lighting. Based on the above calculations, their high potential allows for the remaining produced energy to be used for other possible consumers listed earlier. Therefore, to determine the maximum number of electric vehicle charging stations and/or fuel stations, we will use the following formulas:

$$Er = 4.54A - 0.9A = 3.55A \quad (7)$$

$$\mathrm{Pr\,min} = 3.55A * 220V = 781W \quad (8)$$

$$\mathrm{Pr}\,total = 781W * 201 = 156.9kWh \quad (9)$$

$$Tec\ max = \frac{156.9kWh}{22kwh} = 7.13 \quad (10)$$

$$Tec\ \mathrm{min} = \frac{156.9kWh}{3.7kwh} = 42.40 \quad (11)$$

$$Tsc\ \mathrm{max} = \frac{156.9kWh}{7kWh} = 22{,}4 \quad (12)$$

$$Tsc\ min = \frac{156.9kWh}{28kWh} = 5.60 \quad (13)$$

Er - Remaining electrical energy;
Pr min - Minimum remaining power;
Pr total - Total power remaining after street lighting;
Tec max - Maximum number of recharge stations that can be powered;
Tsc max - Maximum number of fuel stations that can be powered;

5. Conclusions

Following the calculations and the direct addressing of these products for use as a source of non-polluting energy, the idea can be concretized that small vertical-axis wind turbines represent a promising technology for generating electricity using the wind created by highway traffic. This technology can be used to reduce energy costs and contribute to reducing greenhouse gas emissions.

As a result of this study, the question may arise as to why this method of generating electricity would be more efficient than solar panels. For this, the following arguments exist:

1. Small vertical-axis wind turbines are more efficient under the specified conditions (existence of tunnels, viaducts or passages in the highway design significantly increases their efficiency compared to solar panels, which are dependent on areas with strong sun and clear skies. Solar panels also produce much less, or no electricity at all, during the night and are greatly affected by cold periods.

2. Solar panels require a much larger surface area and a higher implementation cost in order to generate the same amount of electricity as a wind turbine.

3. Maintenance: Small vertical-axis wind turbines have fewer moving parts and can also be easily monitored and maintained through automated control systems.

4. Service life: Compared to solar panels or photovoltaic parks, small wind turbines have a relatively long service life, usually over 20 years. Their components are designed to be durable and resistant to wear, and their simple design reduces the risk of failures and the need for costly component replacements.

The use of small vertical axis wind turbines can be successfully integrated into existing infrastructure, which can reduce installation and maintenance costs. Moreover, these turbines are less sensitive to wind direction and speed, making them more suitable for areas where air currents are variable. In addition, these turbines are much more compact and quieter than horizontal axis turbines, making them even more suitable for use in urban areas or on highways.

It is important that the implementation of these turbines is done carefully, and their design is thoroughly analyzed, considering all specific installation conditions to ensure optimal performance and maximum durability. If implemented carefully, these wind turbines can be an efficient and sustainable solution, contributing to reducing the negative impact of road transport on the environment.

In conclusion, small vertical axis wind turbines are a promising technology for generating electric power using wind created by highway traffic, but it is imperative to consider all specific conditions and conduct a comprehensive cost-benefit analysis before implementation.

6. Bibliography

[1]. Wind Turbines along highways: Feasibility study of the implementation of small scale wind turbines along the Prins Bernardweg Zaandam to Bolswarderbaan highway in the Netherlands, De Jong, B.C.P.M. (accessed on 26.04.2023)
[2]. Wind Energy in the built environment - M.A. HYAMS, Columbia University, USA.
[3]. https://www.sciencedirect.com/topics/engineering/vertical-axis-wind-turbine (accessed on 30.04.2023)
[4]. https://www.researchgate.net/figure/Different-kinds-of-vertical-axis-wind-turbines-VAWT-a-Savonius-b-Darrieus-with_fig1_333316757 (accessed on 01.05.2023)