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Development of Wind Turbines used on Iraqi Exterior Highways

Ikram Kamel Abd[1], Shahad Raji Mhel[1], Aseel Kamel Abed[2], Waleed Ibrahim Yaseen[3], and Omar Al-Juboori[3]

[1]Al-Karkh University of Science Baghdad-Iraq
[2]Ministry of Electricity-South Baghdad Power Station, Baghdad-Iraq
[3]Department of Astronomy and Space -College of Science- University of Baghdad, Baghdad-Iraq

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Abstract

The design and production of four-blade vertical turbines for wind power are the subjects of this study. One kind of wind turbine with a vertical axis that is used to generate electricity is the giromill wind turbine. The turbine comprises a primary shaft that rotates and four straight airfoils that depict the blades. The airfoil, main shaft, and bearing of all necessary wind turbine components were developed for the Iraqi exterior highways in this study. Included in the power calculations are torque, TSR, power factor, and wind speed. After the blades are made, all the pieces are assembled from steel, aluminum, and wood components. Ultimately, testing revealed that the turbine was operating very efficiently.

Keyword: Wind turbine, wind velocity, power coefficient.

تطوير توربينات الرياح المستخدمة على الطرق السريعة الخارجية العراقية

اكرام كامل عبد[1], شهد راجي مهيل[1], اسيل كامل عبد[2], وليد ابراهيم ياسين[3] ,عمر طارق علي[3]

[1]جامعة الكرخ للعلوم, بغداد–العراق
[2]وزارة الكهرباء– محطة كهرباء جنوب بغداد, بغداد–العراق
[3]قسم الفلك والفضاء، كلية العلوم، جامعة بغداد، بغداد، العراق

الخلاصه

ان تصميم وإنتاج توربينات عمودية ذات أربع شفرات لطاقة الرياح هي موضوع هذه الدراسة. أحد أنواع توربينات الرياح ذات المحور العمودي المستخدم لتوليد الكهرباء هو توربينات الرياح الجيروميلية. يتكون التوربين من عمود أساسي يدور وأربعة جنيحات مستقيمة تمثل الشفرات. تم في هذه الدراسة تطوير الجنيح والعمود الرئيسي ومحمل جميع مكونات توربينات الرياح الضرورية للطرق السريعة الخارجية العراقية. تتضمن حسابات الطاقة عزم الدوران و نسبة سرعة الطرف وعامل الطاقة وسرعة الرياح. بعد تصنيع الشفرات، يتم تجميع جميع القطع من مكونات الفولاذ والألومنيوم والخشب. وفي النهاية، كشف الاختبار أن التوربين كان يعمل بكفاءة عالية.

1. Introduction

The use of wind energy dates back to hundreds of years. In Scotland, the first windmill used to generate electricity was constructed in 1887. Innovative initiatives ensued in many

*Email: Ikram.kamel@kus.edu.iq

European and American nations. The modern form of wind turbines emerged only in the latter part of the 20th century. Wind energy installations have grown rapidly worldwide since the early 2000s. From 100 GW in 2008 to more than 620 GW in 2019, the world’s installed wind capacity increased by more than six times during the previous ten years. With 51 GW added to its capacity in 2018, wind power is the second most widely used renewable energy technology globally, after hydropower. Solar energy is the only technology that has exceeded wind power in terms of capacity additions (IEA 2020) [1]. Depending on where the turbines are located, onshore and offshore wind energy can be separated. However, as of 2018, 24 GW, or 4.1%, of the installed wind capacity was offshore (IEA 2019) [2].

The kinetic energy of flowing air is converted into electrical power by wind turbines. When wind turbine blades are rotated, the turbine itself is turned. Electrical energy is produced by the generator's shaft being moved by this rotational energy.

Three essential parts make up a modern wind turbine: the tower, the nacelle, and the rotor blades. The turbine's central component is the nacelle. It incorporates the gearbox, generator, and rotor hub as part of the machine set. A shaft connects the rotor blades to the gearbox, and occasionally to the generator directly as well. With the use of electrical equipment, one may modify the blade angle to maximize production in varying wind conditions and restrict the amount of power generated at high wind speeds. Without getting into technical specifics, wind turbine power production is primarily determined by two factors: wind speed and rotor blade length. Increasing the blade length multiplies the wind power potential of a wind turbine because the rotor blade swept area determines the amount of electricity produced by the machine. Additionally, the energy output increases in direct proportion to the wind speed's third power ($E=1/2\rho AV^3$) .

Thus, doubling wind speed results in an eight-fold increase in power potential. Considering that wind speeds typically increase with height from the ground, this suggests that the hub height, or the length of the tower, is an important design parameter for wind turbines. Therefore, taller towers typically result in higher wind turbine yields.

In addition to altitude above the surface, wind speed varies greatly by location. Thus, the installation's location is crucial to the economics of wind energy. Higher wind speeds generally benefit coastal regions more than landlocked ones. This is what motivates the installation of offshore wind turbines in spite of their much higher costs and technical complexity. The majority of offshore wind turbines are fixed; they are hardly ever floating. Fixed turbines are only used in shallow coastal areas because their foundation is on the ocean floor [3].

One of the most alluring renewable energy sources is wind power, due to its excellent efficiency and low pollution [4]. The WECS's power output varies according to the weather and wind speed in the atmosphere [5]. As a result of the increased need for primary reserves, unexpected variations in WECS power generation could raise operating costs for the electrical system and potentially jeopardize the supply of reliable electricity [6]. Accurate wind speed measurement is necessary in order to decrease the hold limit and increase wind infiltration [7]. In order to combat climate change and ensure energy security, nations throughout the world are currently placing a greater focus on the development of clean energy and enhancing energy efficiency. High efficiency, low carbon, and clean energy are the emerging trends in global energy. Smart grid technology has been rapidly developing in many countries in recent years as the foundation and premise of low-carbon electricity. The development trend for the future grid is the smart grid [8].

In this work, a wind turbine will be developed for use on highways to generate electrical power for devices spread on these roads. This turbine depends on the wind generated from fast car traffic, which generates intense air vortices that move the turbine's fins. A structure will be added to the turbine containing two opposite gates, where each wind gate will face the opposite direction, which will limit the wind towards the turbine fins, which will increase the wind speed and thus increase the turbine speed and efficiency. In addition, an upgraded generator will be used to increase generation efficiency.

2. Wind Energy

Wind energy represents a renewable energy characterized by its low cost and abundance of resources. For these reasons, many countries have begun using this clean energy. The annual growth rate of wind energy has increased to 30% in developed countries, according to global statistics [9]. Wind energy represents an advanced energy technology as it generates electrical energy from wind energy and has begun to play an essential role in the global energy industry [10]. To calculate the potential energy of wind movement around the wind power generator developed in this work, some concepts must be simplified and the wind must be considered ideal, that is, unturbulent and with one horizontal direction. Furthermore, winds are assumed to be incompressible, meaning their density remains constant [11]. Also, air density was considered constant everywhere, and humidity, temperature, and altitude affect air density. The average value of air density is $\rho_{Air} = 1.25$ kg/m^3 [12]. The wind energy equation can be written as [13]:

$$E = \frac{1}{2}\rho_{Air}Av^3 \tag{1}$$

Where the turbine's swept area is A [14].

Determining the blades' wind power is an important stage that requires [15]:

$$P = \rho_{Air}Av^3 \tag{2}$$

Where P= Wind power (watts).

To calculate the power input, you can use:

$$P_{in} = \frac{1}{2}\rho_{Air}Av^3C_p \tag{3}$$

The power coefficient, denoted by the symbol C_p, is contingent upon the type of machine and the relationship between wind speed and blade circumferential speed. [16]. In order to calculate the wind speed, the following equation is used:

$$v = v_o\left(\frac{h}{h_o}\right)^n \tag{4}$$

Where V is the wind speed (m/s) at a given height. Vo is the given wind velocity at heights h=0 (m/s), the wind speed calculation height (h), the starting height (m), and the value n, which depends on the nature of the earth in terms of elevations and depressions on the surface of the earth.

3. Power Coefficient:

Every round, the power output of the wind turbine rotor varies. As a result, the rotor's performance coefficient of power can be obtained by dividing power by the wind speed ratio. Consequently, the power coefficient for the Darrieus wind turbine is determined by [17]:

$$C_p = \frac{P}{\frac{1}{2}\rho v^2 A} \tag{5}$$

Where P represents the power of the rotor.

In addition, the tip of the wind speed ratio (TSR) is determined using [18]:

$$TSR = w\left(\frac{R}{v}\right) \tag{6}$$

Where w is the angular velocity (rad/s), R is the rotor radius (mm). v represents wind velocity (m/s)

$$w = (2\pi)\mathrm{rpm} \tag{7}$$

Where pi = 3.14, rpm= radius per minute
Torque coefficient is defined by:

$$C_t = \frac{T}{\frac{1}{2}\rho v^2 A} \tag{8}$$

Where T= Rotor torque
These two coefficients have a relation by [19]:

$$C_t = \frac{C_p}{\lambda} \tag{9}$$

4. Betz's Law:

Power output is determined using [20]:

$$\frac{P_o}{P} = \frac{1}{2}(1 - \left(\frac{V_2}{V_1}\right)^2 \left(1 + \left(\frac{V_2}{V_1}\right)\right) \tag{10}$$

Where P represents power extracted by wind, P_o is undisturbed power. Since Betz's law is not dependent on the design of wind turbines in an open flow, it can be used to determine the maximum power generated by the wind. The law is distinct from the mass-momentum conversion theory of air passing through a blade created by wind. It was established by the German physicist, Albert Betz.

5. Rotor Components

Giromill rotors are comprised of four components:
1) Axis of rotation: The central mast is its definition. It is encircled by the other parts and located in the middle of the rotor. It has a round form and is often metallic.
2) Blades: The Giromill rotor features Darrieus-style vertical airfoil blades. The Giromill rotor blades, however, are straight. The blade's primary purpose is to spin due to wind force. The rotor shaft, which is attached to and spins simultaneously with these blades, is where they are secured and placed. The number of blades is a significant problem.
3) Radial arms: The blades are attached to the central axis of rotation by means of these horizontal supports. They can be welded or threaded and attached to the middle mast and blades.
4) Pulley: This component transfers rotation and torque from the rotor shafts to the generator. The pulley was removed from the washing machine and is composed of aluminum. However, because of its size and shape, it may be employed for our design [21]. A few of the blades profiles proposed by NACA have been chosen for this investigation. The National Advisory Committee for Aeronautics (NACA) standards served as the foundation for the determination of blade profile specifications [22].

6. Aerodynamics of Vertical Axis Wind Turbines (VAWT):

Compared to the horizontal axis model, a turbine shares many comparable characteristics. The plane of the spinning surface of VAWT blades is oriented at an angle of 45 degrees to the direction of the wind. As it spins, the blades' angle of attack fluctuates continuously. In addition, the blade descends the wind side of the other blade at an angle of 180 to 360 degrees in rotation, which lowers wind speed since the higher wind blade is absorbing more energy. Because of this, less power is generated in the lower wind region of rotation. It is evident from flow velocity considerations and aerodynamic forces that the generated torque happens after lift forces have an impact. The drag force is less than the force of lift seen in Figure 1 when the two force components are compared. In addition to some places where the torque is negative, the rotor blade also provides a positive torque. A decrease in positive torque on the wind's lower side is represented by a change in the overall torque.

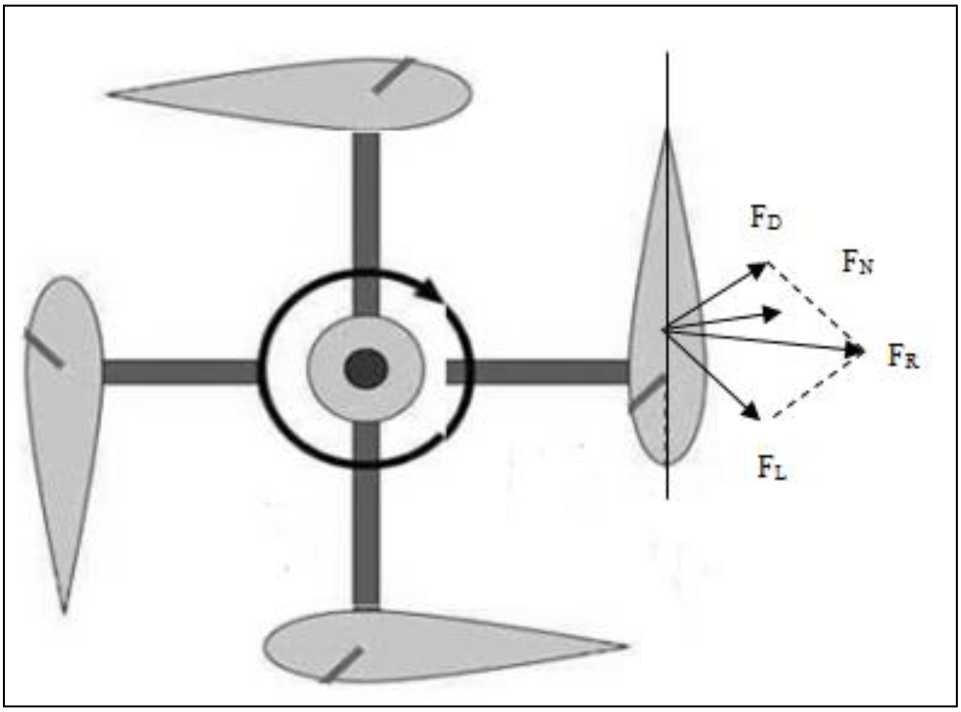

Figure 1: Rotor rotation directions; drag and lift forces.

Three rotor blades can also be used to balance the torque with variations in revolution, allowing the torque to grow and decrease with positive change. On the other hand, if a vertical-axis rotor has a peripheral speed and is not self-starting, torque can be applied to the rotor. Analysis of the conditions of flow for the vertical axis rotor revealed that the computations may be more difficult than for the fan type. Put another way, more sophisticated mathematical and physical computations are used in the production of power [23].

7. Design of Wind Turbine

The vertical wind turbine is shown in Figure 2. The wind turbine includes seven components:
Airfoil, Radial arms, Shaft, Bearings, Screws, Support, and Generator.

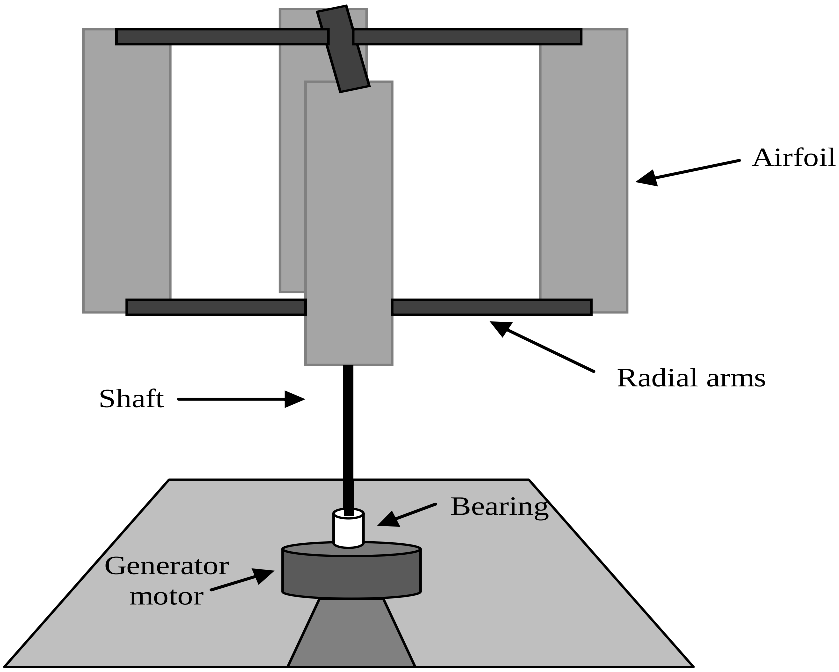

Figure 2: Rotor Parts

7.1 Airfoil of Giromill VAWT

A four-digit NACA wing sector airfoil type has been researched for our Giromill wind turbine design. A string of digits that come after the term "NACA" is used to characterize the form of this type of NACA airfoil, which is an airfoil shape created by the National Advisory Committee for Aeronautics for aircraft wings. To accurately create the airfoil cross section and compute its characteristics, in the numerical code, the parameters found may be inserted into equations. The higher degree of stress is represented by the first number. The second figure shows the maximum tension that the airfoil produced, which accounted for 10% of the total tension. The latter two figures indicate the airfoil's maximum thickness expressed as a percentage of stress. Specifically, the study has examined a uniform four-number NACAs airfoil called the NACA airfoil. These airfoils' primary characteristic is that they have two 0 numbers in the beginning. The NACA form equation for the 00xx model, which substitutes a thickness % for the xx, is as follows:

$$y = \frac{t}{0.2} c \left[0.2969\sqrt{\frac{x}{c}} - 0.1260\left(\frac{x}{c}\right) - 0.3516\left(\frac{x}{c}\right)^2 + 0.2843\left(\frac{x}{c}\right)^3 + 0.1015\left(\frac{x}{c}\right)^4\right] \quad (11)$$

Where t is the maximum thickness, y is the half of the thicknesses at a particular location (from centerline to surface), c is the chord length, and x is the position across the chord from 0 to c.

The aforementioned equation is essential for creating coordinates from a single set of points to construct airfoils using programs like Gambit. In order to analyze these NACA airfoils uniformly in two dimensions:

The selected primary NACA airfoils were: NACA 0012, NACA 0015, and NACA 0020. Previous research on the Giromill VAWT has shown that these airfoils have produced a lot of positive outcomes. To link with the radial arms, the airfoil includes holes on both its top and bottom surfaces. Figure 3 makes this rather evident. Based on earlier research on the Giromill wind turbine, 40% of the chord from the front end is where the drill should be placed.

7.2 Radial Arms

The radial arm refers to the length of space between the air foil and the central shaft. Installing certain mechanisms makes it simple to assemble and disassemble the shaft and airfoil. Aluminum is utilized in the construction of radial arms due to its high strength and low weight. 6mm screws are used to secure the airfoil to the arms. There are two different kinds of radial arms that are intended to pass through the shaft: one for the top and one for the bottom.

Because of the rotor size and the weight of the blades, we approximated the length of each arm in our design to be 50 cm. Later, we changed the length to reduce arm distortion and improve the wind impact over the blade region. This deformation results from the arms bending when there is a lot of force applied to the rotor's construction.

7.3 Shaft

A shaft is a revolving machine component that transfers power from one location to another. Some tangential force provides the power to the shaft, and the torque that is created inside the shaft enables the power to be transmitted to other machines that are connected to the shaft. Power is transferred between shafts by the use of different elements installed on them, including gears and pulleys. The shaft rotates as a result of these components and the forces applied to them. Stated differently, the shaft transfers both torque and bending moment. Keys or spines are used to install the different parts on the shaft.

The shaft's section might be square or cross-shaped, although it is often cylindrical. Although they have a solid cross section, hollow shafts are nevertheless occasionally utilized. Although it has a form with the shaft, an axle is a fixed machine part that is solely employed to transmit bending moments. It just serves as support for a spinning body, such as a rope or a drum being hoisted within a car wheel. A short shaft that affects motion is called a spindle.

7.3.1 Power:

The power is represented by:

$$P = \frac{2\pi NT}{60} \tag{12}$$

7.3.2 Torque:

Represented by:

$$T = Wr \tag{13}$$

Where r= 60cm =0.6 m and W=sum of weights of airfoils.

7.3.3 Load:

Represented by:

$$W = W1 + W2 + W3 \tag{14}$$

The weight of airfoils is represented by:

$$W = 4W_1 \tag{15}$$

7.4 Bearings

A bearing is a tool that allows two components to move relative to each other in a restricted way. This movement is usually linear or rotational. We chose bearing type 6005 in our project and the shaft's diameter is 25 mm.

8. Results and Discussion

8.1 Airfoil Calculations

The following formula needs to be considered in order to get the airfoil's coordinates, much like in equation (11). For N-A-C-A 15: Thickness or t= 0.15 of CHORD LENGTH, where c=15cm T= 15x0.15 = 2.25 cm, the distance of the CHORD changing from 0 to 15. The distance of the chord is listed in Table 1.

By applying equation (11), when x_1=0 cm, then y_1= 0; when x_2=0.10229 cm, y_2 =0.265976 cm; and when x_3=0.406371cm, then y_3=0.508524 cm.

The calculations are done for 20 values, and the results are listed in Table 1. Figure 3 shows the model of the airfoil.

Table 1: Airfoil coordinates

x	y upper	x	y lower	x Camber Line	y
0	0	0	0	0	0
0.10229	0.265976	0.10229	-0.265976	0.10229	0
0.406371	0.508524	0.406371	-0.508524	0.406371	0
0.903947	0.720849	0.903947	-0.720849	0.903947	0
1.581446	0.894727	1.581446	-0.894727	1.581446	0
2.420388	1.022645	2.420388	-1.022645	2.420388	0
3.397889	1.09976	3.397889	-1.09976	3.397889	0
4.487284	1.125133	4.487284	-1.125133	4.487284	0
5.658859	1.101947	5.658859	-1.101947	5.658859	0
6.880655	1.03679	6.880655	-1.03679	6.880655	0
8.119345	0.938385	8.119345	-0.938385	8.119345	0
9.341141	0.816251	9.341141	-0.816251	9.341141	0
10.512716	0.679735	10.512716	-0.679735	10.512716	0
11.602111	0.537591	11.602111	-0.537591	11.602111	0
12.579612	0.398028	12.579612	-0.398028	12.579612	0
13.418554	0.268954	13.418554	-0.268954	13.418554	0
14.096053	0.158062	14.096053	-0.158062	14.096053	0
14.593629	0.072557	14.593629	-0.072557	14.593629	0
14.89771	0.018503	14.89771	-0.018503	14.89771	0
15	0	15	0	15	0

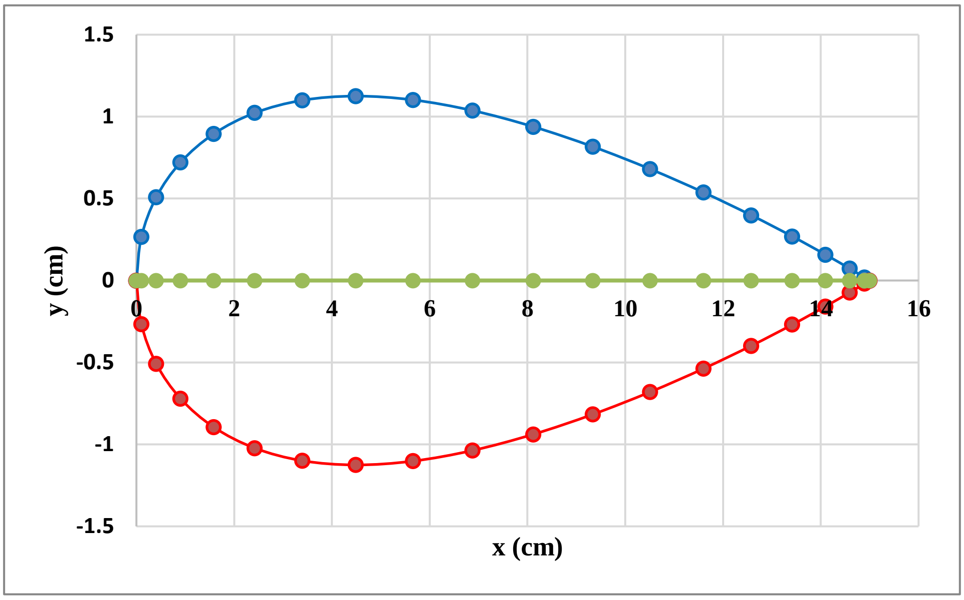

Figure 3: Excel sketching of the airfoil

8.2 Calculation of the Shaft

$A = \frac{\pi}{4} d^2 = \frac{\pi}{4} * (0.0025)^2 = 0.0000049\ m^2$ is presented as a cross-sectional area of the shaft.

The weight of airfoils is represented by equation (14), and the airfoil 1 weight W_1 is equal to:

W_1=0.50 kg, W_1=0.50x9.81= 4.905 (N), and W =4x4.905 =19.62 (N).

The radial arm weight can be negligible, r=60cm=0.6 m, and by using equation (13), the Torque can be calculated: T=19.62x0.6 =11.772 N.m.

When N=30 rpm by equation (12), the power can be calculated: P=36.964 Watts.

8.3 C_p Calculations:

The power coefficient can be calculated by using equation (5).

V=8.00 m/s; therefore, P_1= 0.5x (1.225 kg/m^3) x (0.98m^2) (8^3) =307.328 Watts; C_p1= 12/307.328 = 0.039.

We can conduct some tests to ascertain the efficacy of the system that can be produced. In addition, we measured the blades' power output. Figure 4 illustrates how the results of the power of coefficient test vary with wind velocity, with C_p decreasing with increasing velocity. Figure 5 presents the C_P that varies with TSR for three values of angle of attack; these results agree with [24].

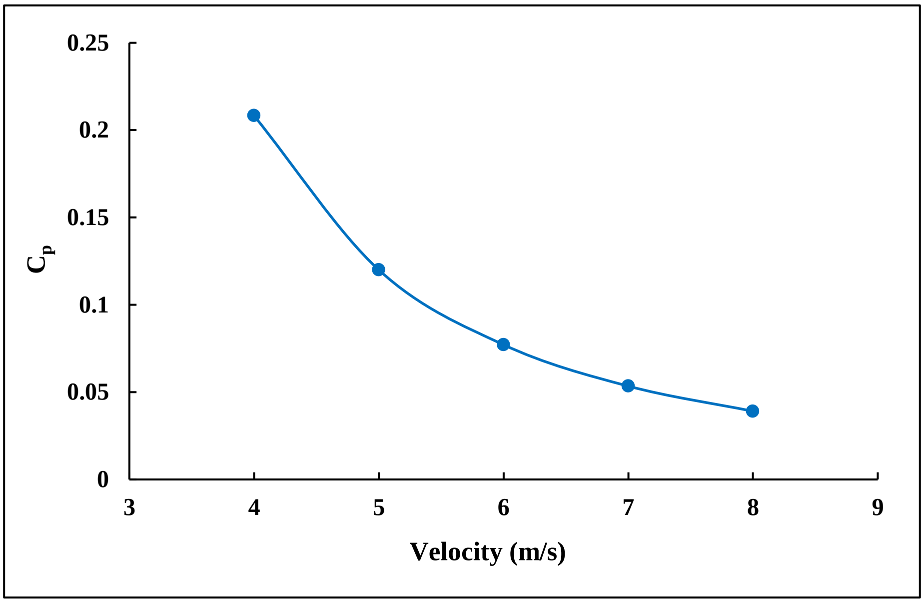

Figure 4: Power of coefficient vs. velocity of wind.

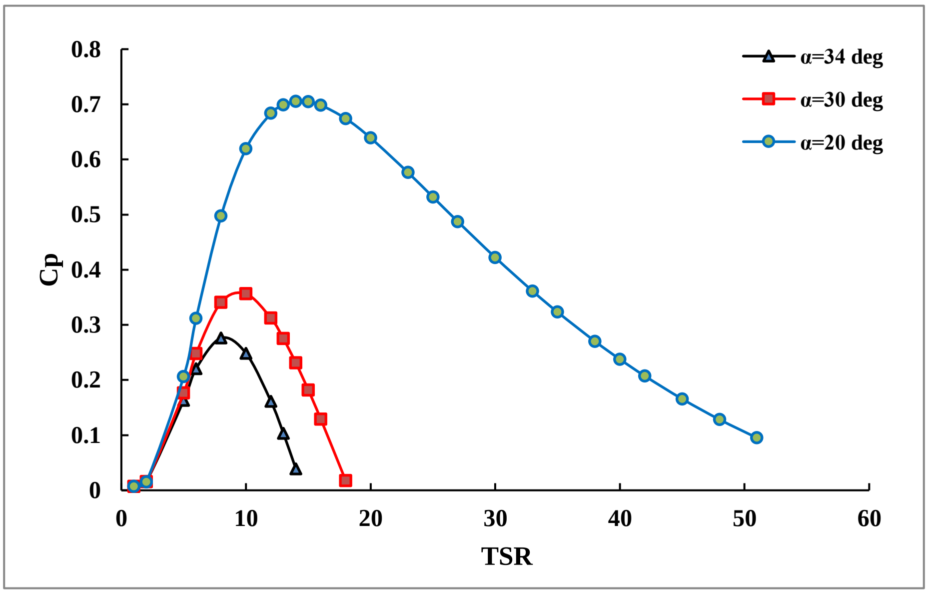

Figure 5: Power of coefficient vs. Tip speed ratio for three values of angle of attack.

A decrease in the angle of attack (α) leads to an increase in the coefficient values of C_P and the TSR range is high. When the wind speed is at its highest level, the speed of the rotor should be at its highest, and the generation of electric current should increase. We should take two hours' worth of data in order to obtain the best possible outcome for our rotor speed. The data show that the wind speed ranges from 4 to 8 m/s. Figure 6 shows how power changed as wind speed increased. When velocity rose, power rose as well, according to equation (2).

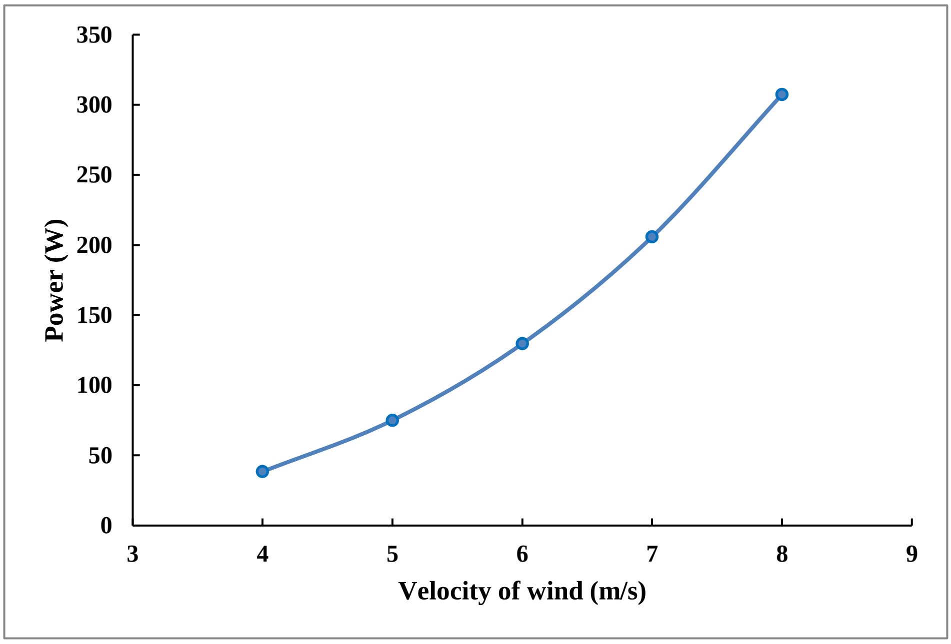

Figure 6 Powers vs. velocity of wind

It is possible to select an electric scooter motor generator that runs on DC, which increases the difficulty of our design and needs more torque to operate. While producing less electricity, this approach can serve as both a workaround for our situation and a demonstration of the viability of wind power.

9. Conclusions

Many calculations and research for suitable wind turbines were carried out in this work before the design was chosen. We have learned a lot about wind energy from careful examination of the workings of wind turbines that were manufactured and developed to operate on wind generated by automobile traffic on highways. From the results, it was noted that power generation was continuous, even if there was no wind in the air, because the turbine's working principle depended on the movement of cars. This information will help us carry out the practical part of the design, understand the properties of the materials we are working with, and understand how the wind turbine parts are put together. In addition, the theoretical part helped us choose the appropriate materials and operating conditions for the Giromill wind turbine, including wind speed, location, and safety factors.

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