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Design and development of a comprehensive renewable energy system

Diseño y desarrollo de sistema integral de energías renovables

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Abstract

The electrical energy supplied by the Federal Electricity Commission (CFE) in Mexico suffers from disconnections due to failures due to overloads, short circuits or vandalism; leaving the user without this service for minutes or even for a few hours. Through the analysis by Quality Functions Deployment (QFD) we proceeded to the development of this work, the performance of a vertical position wind generator is designed and analyzed by software for the estimation of initial parameters, which due to its design Savonius multi-blade type makes it ideal for areas with very slow winds and speeds below 10 m/s. In order to meet the generation and energy saving needs, the implementation of a park of three vertical generators that will have the capacity to supply electrical energy to homes, offices or luminaries in public parks proposed. Finally, it is an opportunity to achieve one of the challenges set out in the 2030 sustainable development agenda and thereby guarantee one of the main objectives, which is universal access to energy services.

Renewable energy, Eolian, Electricity generation, Savonius, Wind

Resumen

La energía eléctrica suministrada por la Comisión Federal de Electricidad (CFE) en México, sufre de desconexiones debido a fallas por sobrecargas, cortocircuito o vandalismo; dejando al usuario sin este servicio por minutos o incluso por algunas horas. Mediante el análisis por Despliegue de Funciones de Calidad (QFD) se procedió a el desarrollo de este trabajo se diseña y se analiza mediante un software el desempeño de un generador eólico de posición vertical para la estimación de parámetros iniciales, los cuales debido a su diseño tipo Savonius multiaspas lo hace ideal para zonas con vientos muy lentos y con velocidades por debajo de los 10 m/s. Para atender las necesidades de generación y ahorro de energía, se propone la implementación de un parque de tres generadores verticales que tendrán la capacidad de suministrar energía eléctrica a hogares, oficinas o luminarias en parques públicos. Finalmente, es una oportunidad para lograr uno de los desafíos planteados en la agenda 2030 de desarrollo sostenible y con ello garantizar uno de los principales objetivos que es el acceso universal a servicios energéticos

Energía Renovable, Eólico, Generación eléctrica, Savonius, Viento

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Introduction

The theory of aerodynamics developed during the first decades of the 20th century, allowing us to understand the nature and behaviour of the forces that act around the turbine blades. In Russia, Joukowski, Drzewiechy and Sabinin, in Germany, Prandtl and Betz, in France, Constantin and Enfield were some of the scientists who developed the theory of aerodynamics for aeronautical uses and established the basic criteria that the new generations of turbines had to meet wind.

In 1927, Betz demonstrated that the performance of turbines increased with the speed of rotation and that in no wind system could exceed 60% of the energy contained in the wind. The theory also showed that the higher the rotational speed, the less important the number of blades was, so a single-blade turbine can built without significantly decreasing its aerodynamic performance.

The project focused on the production of electrical energy through a hybrid model of alternative energy from wind and solar energy (Lee, 2023), showing efficiency and a reduction in energy dependence on the supply company. As well as avoiding the production of polluting gases, effluent liquids, solid waste and the use of a hydraulic flow to generate electricity in a conventional way (Zheng, 2023).

The annual variation of the wind was approximated using the accessibility of the wind in the area (see image 1) and proposing as a viable alternative the vertical design that favors it (see Figure 2), since it has the capacity to work well at low heights. (Venture, 2023)

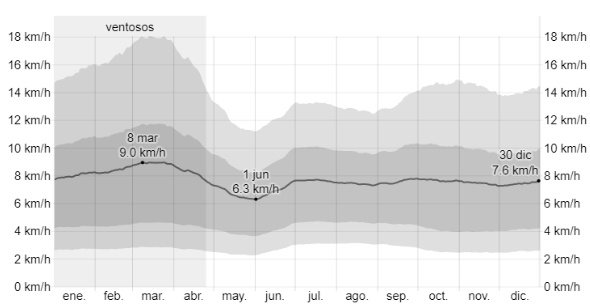

Figure 1 Average wind speed in the Chalco area during the course of the year
Source: Wheaterspark, 2023. (Venture, 2023) Both general and synoptic winds are linked to atmospheric circulation and maintain the same characteristics over large areas of land (Orozco,2014)

Using the principle of lift, Betz's law (López, 2013) and the principle of electromagnetic induction, we proceed to the CAD analysis (see image 2) and continue with the construction of a compact and efficient wind turbine. Using the principle of lift, Betz's law (López 2013) and the principle of electromagnetic induction, we proceed to the CAD analysis (see Figure 2) and continue with the construction of a compact and efficient wind turbine (Rivkin, 2013).

Figure 2 Design made in mechanical and architectural design software
Source: Own elaboration

For the correct use of general winds and the location of machines, the Bjerknes axiom taken into account, which indicates the movement or direction of rotation: "when the pressure gradient and the temperature gradient have different directions, a circulation occurs of air from the pressure gradient to the temperature gradient (Cueva, 2015).

While the synoptic winds allow to schematize its movement by a vector oriented in the direction towards which it blows and whose origin is located in the place of observation. The regional winds governed by synoptic type displacements of the air mass, which is finer and more precise than the general circulation of Hadley and whose characteristics are determined based on given and very precise meteorological situations; such as the isobaric configuration and the position of the fronts.

The direction of the wind at ground level is influenced by the topographic situation of the considered place, the frequency of the directions is not always a general characteristic in line with the average isobaric situation, as is the respective average position of anticyclones and depressions along of the year, the particular and local winds are proof of this.

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Methodology

The calculation, design and construction memory of a vertical generator prototype developed based on wind statistics in the eastern part of the state of Mexico, particularly in the town of Chalco. The relevant calculations for this work were: area of the blades, gear ratio, rotation speed, the generator, the required power, the electric power according to the Bentz efficiency (for the wind turbine), the power of the solar panel and the total power of the system. Within this project, the materials that initially used for the blades were glass wool, catalyst and resin; obtaining a porous surface that presented more resistance to the passage of the wind. The solution for this mishap was to use commercial fiberglass plates, since these plates have a smooth surface and are ideal for prototyping.

QFD

Quality Function Deployment (QFD) used worldwide as a methodology that translates the voice of the customer into design parameters so that they can be deployed horizontally within planning, engineering, manufacturing, assembly, and service departments. (Gonzalez, 2001)

This methodology used in the present project since it helped to identify what is important and thereby provide a system based on logic and thus replace decision-making based on emotions.

The quality house for this project consists of the eight base areas of the QFD, those numbered from one to four make up the basic parameters and the following four originate their relationship matrices (see Figure 3) (Hunt, 2013)

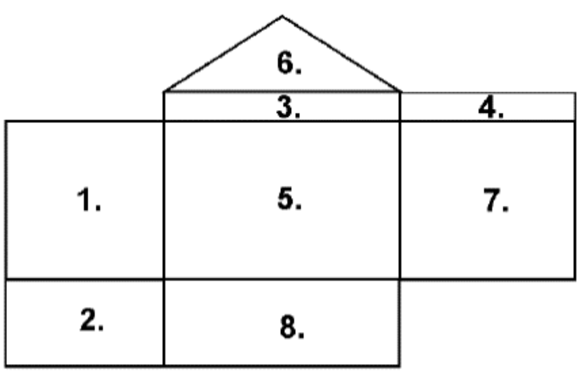

Figure 3 General scheme of the QFD quality house of the proposed wind turbine
Source: Own elaboration

The areas and matrices listed in Figure 3 are:

1. User requirement area.

2. Technical evaluation area.

3. Area of quality characteristics.

4. Evaluation factor area.

5. Correlation matrix.

6. Sensitivity matrix.

7. Evaluation matrix.

8. Scoring matrix.

Figure 4 shows the four main areas and the four matrices applied to the wind turbine that developed in this work. This methodology applied with the purpose of having a product developed in a preventive way and having a very small number of corrections. When developing the engineering specifications, measurable parameters were established based on the characteristics of a wind turbine, therefore, it was investigated in order to obtain the values or characteristics of each of the competitors that met each of the specifications of previously established engineering. The satisfied engineering objectives are the values that the new equipment to be designed should present, while the unsatisfied ones are values that the new equipment should not present (Ullman, 2010).

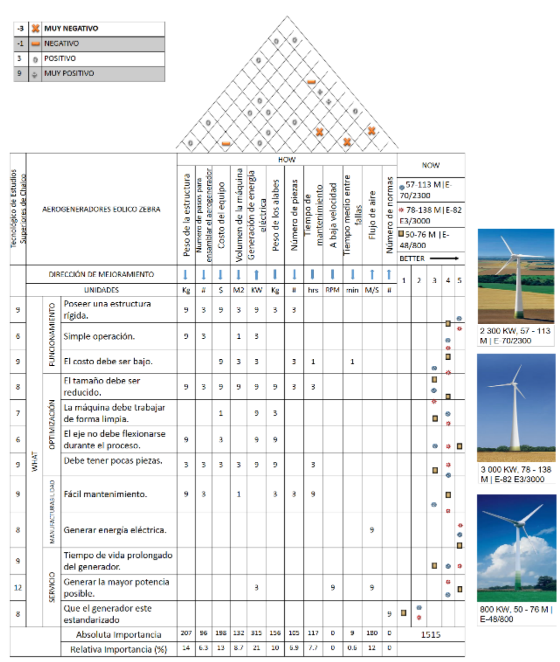

Figure 4 QFD quality house of the proposed wind turbine
Source: Own elaboration

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The criteria for the direction of improvement shown in image 4 "to make it easier to attach requirements" can be measured by the number of steps needed to attach, the time to attach, the number of parts and the number of standard tools used.

An important point here is that every effort should be made to find as many ways as possible to measure customer requirements. A possible solution is to divide the requirement into finer independent parts or to redo the customer needs identification step with specific attention to that requirement, especially in the detailed design and thereby achieve a competitive team proposal.

Results

Wind power

The average speed in Chalco is 6.3 km/h, equivalent to 1.75 m/s (Ventures, 2018), which is the tangential speed of our turbine. And a blade radius of 0.50 m is proposed. Having these variables, we proceed to calculate the value of the angular velocity using equation 1. 8 (Orozco,2014)

$$v = w.r \quad (1)$$

Where; v is the average velocity, r is the radius of a blade, and ω is the angular velocity.

Solving for angular velocity, we get:

$$w = \frac{(1.75)(60)}{1} = 105\ rpm$$

Therefore, if we use mechanically with a 6 to 1 ratio band, the angular speed will be raised to 630 rpm.

For the calculation of the power, because you are working with a fluid, you must calculate the wind flow, this is done using equation 2.(Orozco, 2014)

$$Q = A * v \quad (2)$$

Where; Q is the flow rate, A is the area of one of the blades, and v is the average velocity.

$$Q = \left(1.75\ \frac{m}{s}\right)(0.782\ m^2) =$$

$$Q = 1.37\ \frac{m^3}{s}$$

In addition, to calculate the power we will use equation 3.

$$P = Q\rho gh \quad (3)$$

Where; P is power, Q is the flow rate, ρ is the air density, g is the gravitational constant, and h is the ideal height.

$$P = \left(1.37\frac{m^3}{s}\right)\left(1.225\frac{kg}{m^3}\right)\left(9.81\frac{m}{s^2}\right)(10\ m) =$$

$$P = 164.63\ \text{W}$$

According to the Betz efficiency, a wind turbine has an efficiency of 40%, equation 4 (López, 2013)

$$P = (164.63\ W)(0.40) = 65.852\ W \quad (4)$$

Therefore, our power is 65,852 W, but multiplying this power by the five blades that our turbine has and by a time period of 24 hours (equation 5), we obtain (Talavero, 2011).

$$P = (65.852)(5)(24\ ) = 7.9\ kW/h \quad (5)$$

The total power produced in the turbine will be: 7.9 kW/h

According to the calculations proposed, the use of 5 blades would generate more power increasing the surface area where the wind currents impact.

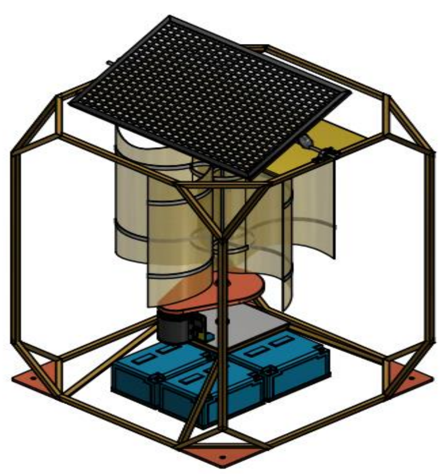

Figure 5 Design with 5 blades

For the analysis of the results, the aerodynamic theory of machines considered, in which one of the first considerations is the drag force:

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$$F_{arr} = R * sen \propto = K_x * S * V_2 * F_{asc} = R * cos \propto = K_y * S * V_2 \quad (6)$$

Where:

The force R considered normal to the chord of the profile, which is at the same time its characteristic length; the buoyancy increases as α decreases. The chord considered from the leading edge of the air foil to the trailing trailing edge. If the shape of the profile is not flat, R can be decomposed based on two types of coefficients, drag kx, and lift ky, with the x axis parallel to the wind direction.

The axial force and the torque evaluated from

$$dF_{par} = dR_y sen\theta - dR_x cos\theta = \frac{1}{2}\rho(c^2)dS(C_y sen(\theta) - C_x cos(\theta)) \quad (7)$$

Being θ the angle formed by the apparent (relative) wind direction. The values involved in the calculation of these differential elements are a function of the speeds in each zone [Figure 1] and, therefore, of the angle of attack α, since this is known, it is possible to obtain the values of Cx and Cy as a function from it, getting:

$$dF_{par} = \frac{1}{2}\rho v^2 dSC_y \frac{sen\ (\theta - \alpha)}{sen^2\theta cos\alpha}$$

$$dF_{par} = \frac{1}{2}\rho v^2 dSC_x \frac{cos\ (\theta - \alpha)}{sen^2\theta cos\alpha} \quad (8)$$

The equation for the centrifugal force responsible for providing the thrust on the blades towards the outside, is taken into consideration since it could tear the blades from the hub:

$$F_{cent} = \frac{1}{2} G \frac{u^2}{r_G} = \frac{G(\frac{\pi r_G n}{30})^2}{2r_G}$$

$$F_{cent} = \frac{0.1034G\{(kv(SR)_G\}^2}{2r_G} \quad (9)$$

The calculation of the force generated by the wind and the speed was carried out with the help of a CFD tool (Computational Fluid Dynamics) which shows the maximum result of 6 m/s for the use of 5 blades while maintaining structural stability.

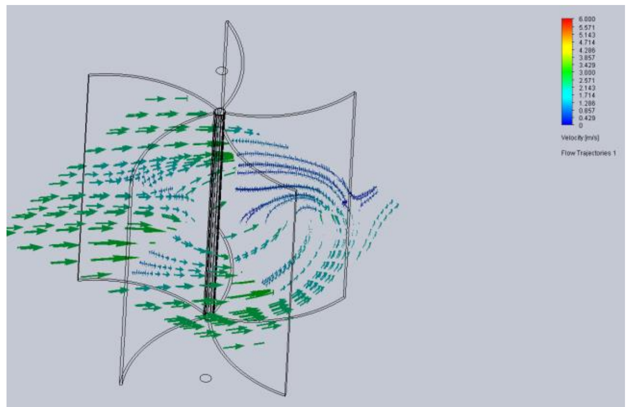

Figure 6 CFD Test for velocity

In the same way, using the CFD tool, the maximum pressure generated in the blades obtained, which is very close to atmospheric pressure, for which it observed that the integrity of the blades would not be affected.

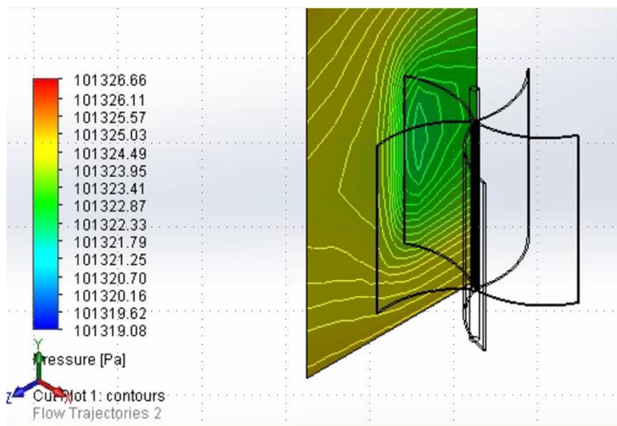

Figure 7 CFD Test for pressure

Solar energy: the solar cell under standard conditions provides us with a maximum power of 250 W per hour, so a period of 8 hours considered:

$$P = (250\ W/h)(8h) = 2\ kW/h$$

If it is considered that during those 9 hours the temperature exceeds 25°C and under these conditions the efficiency drops to 88%, then:

$$P_{88\%} = (2\ kW/h)(0.88) = 1.76\ kW/h$$

Considering that there could be very cloudy days, the efficiency would drop up to 25%, leaving:

$$P_{25\%} = (2\ kW/h)(0.25) = 0.5\ kW/h$$

Therefore, the maximum and minimum power considered on a sunny day and a cloudy day respectively, calculating the average power.

$$P_{prom} = [(1.76 + 0.5)kW/h]/2 = 1.13\ kW/h$$

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Total power:

With the calculation of the power of wind and solar energy (Le, 2023), the total power of the hybrid system estimated, obtaining a value of 9.03 kW per hour.

$$P_{total} = 7.9 + 1.13 = 9.03\ kW/h$$

As can be seen in the calculations, the power generated can satisfy various needs, so its use is suitable in offices, 1-story houses, and even in 2-story houses.

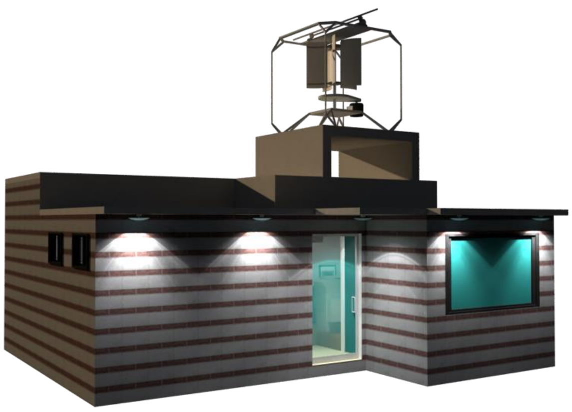

Figure 8 Example of use in offices

On average in Mexico, a single-family home consumes 6.59 kW/h according to the World Data Bank, less than the 9.06 kW/h calculated for the total power generated for the proposed system.

Figure 9 Example of use in houses

Conclusions

It was observed that the surface of the blades should have the lowest possible roughness, which is why the lowest roughness [image 2] was used as design for the material of the product through computer programs such as SolidWorks and Revit since the roughness will depend on the material and depending on a lower roughness coefficient, the drag generated by the blade will be less. Based on the material used in this work, there is a roughness coefficient of 0.1 mm.

Another observation that made was that for greater wind efficiency, the wind turbine could be placed in areas close to roads with a large influx of vehicles, so as a second stage it is intended to develop new prototypes in these areas to optimize the generation of electrical energy.

References

Cueva, B., 2015. *Diseño y construcción de un generador eólico de eje vertical tipo Savonius para producir 20W.*. Escuela Politécnica Nacional ed. Quito : s.n.

Gonzalez, M. E., 2001. *QFD La función despliegue de la calidad; una guía práctica para escuchar la voz del cliente.*. Mc Graw-Hill ed. México : s.n.

Hunt, R. X. F., 2003. *The leading adge in strategic QDF.* West Yorkshire ed. England : s.n.

Le, TS, Nguyen, TN, Bui, DK y Ngo, TD (2023). *Optimal sizing of renewable energy storage: A techno-economic analysis of hydrogen, battery and hybrid systems considering degradation and seasonal storage*. Applied Energy, 336,120817.

Lee, J., Lin, KYA, Jung, S. y Kwon, EE (2023). *Hybrid renewable energy systems involving thermochemical conversion process for waste-to-energy strategy*. Chemical Engineering Journal, 452, Part 2, 139218.

López, M., 2013. *Ingenieira de la Energía Eólica.* Alfaomega ed. México : Marcombo.

Orozco,M. E., 2014. *Comparacion de herraminetas de diseño para alabes de aerogeneradores eólicos de baja velocidad de viento.* Universidad Autónoma del Estado de Hidalgo ed. Pachuca, Hidalgo: s.n.

Rivkin, D. e. a., 2013 . *Wind Turbine Technology and Desing.* Jones & Barllet Learning ed. United States of America : s.n.

Talavero, N. &. T. M., 2011. *Energía Eólica.* Universitarias de Zaragoza ed. España : Prensas.

Ullman, D., 2010. *The mechanical desing process.* McGraw-Hill ed. Michigan, United States of America: s.n.

Ventures, C., 2018. *Wheaterspark.* [En línea] Available at: https://es.wheaterspark.com/y/6691/Clima-promedio-en-Chalco-México-durante-todo-el-año
[Last access: July 13, 2023]

Zheng, J., Du, J., Wang, B., Klemeš, JJ, Liao, Q. y Liang, Y. (2023). *A hybrid framework for forecasting power generation of multiple renewable energy sources*. Renewable and Sustainable Energy Reviews,172,113046.

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