Design and Implementation of Wind-Powered Charging System to Improve Electric Motorcycle Autonomy

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Abstract. The careless use of fossil fuels for decades has had a negative effect on the environment, which has led to addressing climate change as one of the greatest challenges of our time. Electric mobility is an option to reduce CO2 emissions, but its main disadvantage is its limited range. As well, one alternative for reducing global warming is to use clean energy. In this sense, wind energy is one alternative to clean energy sources, because it does not produce greenhouse gas emissions or air pollutants that contribute to climate change and air pollution. It is also abundant and increasingly cost-effective, making it an attractive option for electricity generation. In this paper, we propose a charging system that harnesses gusts of wind hitting the front of an electric motorcycle and converts their kinetic energy into mechanical energy to produce alternating current through a three-phase generator connected to a propeller system. This research seeks to develop a wind generator that is installed on the front of an electric motorcycle to generate electricity, which is stored in an auxiliary lead acid battery. A Computational Fluid Dynamic (CFD) simulation was performed to visualize the behaviour of the propeller system when exposed to a wind flow. The optimised prototype was implemented using 3D printing, along with the fabrication of metal parts to support the structure. As a result, it was feasible to create alternating current using the suggested prototype, achieving an increase of motorcycle autonomy by 5 to 10%.

The blade system managed to generate an acceptable amount of current, operating in wind regimes higher than 5 m/s, which implies good efficiency in power generation. Finally, the prototype has a better performance in straight tracks where high speeds can be reached and consequently a better efficiency in power generation.

Keywords: Wind energy · propeller system · wind generator

1 Introduction

Climate change is one of the greatest challenges of our time, but it is important to mention the indiscriminate use of fossil fuels that has been occurring for decades, with negative effects on the environment. The continuous progress in the development of new

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technologies in the automotive industry has made it possible to transform the energy propulsion system and adapt it to the new needs of using clean energy, which is expected to reduce environmental pollution.

The development of mankind has always been largely determined by the use of different forms of energy according to the needs and availability of each time and place. From the very beginning, the main resources were based on the use of renewable energies in the form of biomass, wind, water and sun. Used mainly as a fuel source, these elements should be considered as the energy base for human development [1].

According to [2] mentions that the massive use of fossil fuels has led to a significant increase of greenhouse gases (GHG), mainly CO2, in the atmosphere of our planet. The accumulation of these gases has made climate change a reality. This phenomenon implies not only a rise in global temperature and sea level, but also a significant increase in the intensity and frequency of extreme weather events.

The year 2020 was disruptive in terms of transportation. In the midst of the COVID-19 health, economic and social crisis, sustainable mobility has become even more relevant as a central element for improving the quality of life and the resilience of cities in the face of unprecedented events, in Latin America and the Caribbean various elements of public policy are adapted to the needs of a new product and service such as electric mobility. For 2020, several countries in the region have set more ambitious climate targets to avoid a global average temperature increase of more than 1.5 degrees Celsius [3].

According to [4], a wind generator for vehicles is based on the use of the air that enters through the front grille of a vehicle when it is moving to produce electrical energy and provide it with greater autonomy. When the vehicle is moving, the air hits the blades, generating a movement that is transmitted to the rotor shaft, which starts the generators that produce electrical energy that is used to recharge the battery set of vehicles that move with electrical energy [5]. The electric car is currently presented as the alternative of the future in terms of urban transportation and brings, as a fundamental consequence, the reduction of environmental pollution in large cities [6]. An electric vehicle (EV) has zero emissions of polluting gases because it relies on batteries to power its engine and does not burn fuel inside. It also requires less polluting fluids such as oil and coolant.

Renewable energy is gaining popularity because it is more economical and efficient than conventional energy sources. New green energy technologies, such as wind energy, are mainly used to maintain environmental sustainability. This study analyzed the asymmetric relationship between wind energy and ecological footprint in the top 10 wind energy consuming countries [7]. Climate change mitigation is a major societal challenge, and renewable energy is a central element in the transition to a low-carbon society. However, the growth of the renewable energy sector has altered landscapes and land-use dynamics, leading to new land-use conflicts [8].

The global installed capacity of wind power, both onshore and offshore, increased from 7.5 GW in 1997 to 743 GW in 2020. In line with this increase in capacity, knowledge of wind energy and its impacts has improved and a number of reviews have been conducted on the subject [9]. With the help of renewable energy, the carbon footprint can definitely be reduced. Wind energy is a renewable energy source because it does not run out when it is used. The utilization of wind energy through a wind turbine and

its excellent conversion efficiency makes the construction of a wind generator feasible [10].

Clean energy resources will be further utilized to enhance sustainability and sustainable development. Efficient technologies for energy production, storage, and use will reduce gas emissions and improve the global economy. Despite the fact that 30% of electricity is produced from wind energy, the connection of wind farms to medium and large power grids still creates problems of instability and intermittency [11]. Researchers [12] mention that the electric vehicle stores energy and uses it when the need for mobility arises, therefore it does not consume energy from the grid at the time of use. The aerodynamic profile has a fundamental importance in the wind generator. In this section, the effects produced by the wind on each surface or airfoil are studied in depth and the forces acting on the entire blade are studied [13].

The electric generator represents the simplicity of an electric motor, where the permanent magnet produces a magnetic flux with a small mass, the magnets are made of samarian and neodymium [14]. The traditional motorcycle brake generates kinetic energy, which is converted into heat. This process is in perfect harmony with the principle of energy conservation. Thus, the motorcycle dissipates part of its kinetic energy in the form of heat during braking, thanks to the friction generated between the brake disk and the brake pads [15]. The existence of charging infrastructure is a key factor in supporting the large-scale deployment of EVs. If there is no network to charge vehicles everywhere, there will be no place for EVs [16]. A battery charger is a device used to provide current or voltage that is stored at the same time. The charging current depends on the technology and capacity of the battery that the electric motorcycle is equipped with [17]. An electric motor controller is used for signal processing and power management, while the processor is activated, allows the motor to start or stop, and enables the electronic components that receive direct commands from the user. It is also equipped with various protection functions, such as those used against voltage drops or overcurrents [18].

1.1 Design and Calculate

The design process can be divided into several key elements, each of which is essential to the proper functioning of the prototype, and some of which are detailed because they are the fundamental basis for the construction of the prototype. The rotor-generator prototype to be designed consists mainly of a horizontal axis motor connected to wind energy collecting blades. After reviewing the necessary information and defining the necessary requirements to obtain the wind load system (see Fig. 1).

The operating phases of the rotor-generator type charging system. This illustration highlights the importance of exploiting the renewable energies present in the environment, in this case the wind energy present in the gusts of wind that hit the front of the electric motorcycle, generating a kinetic force that is received by a system of blades connected to a three-phase generator (see Fig. 2).

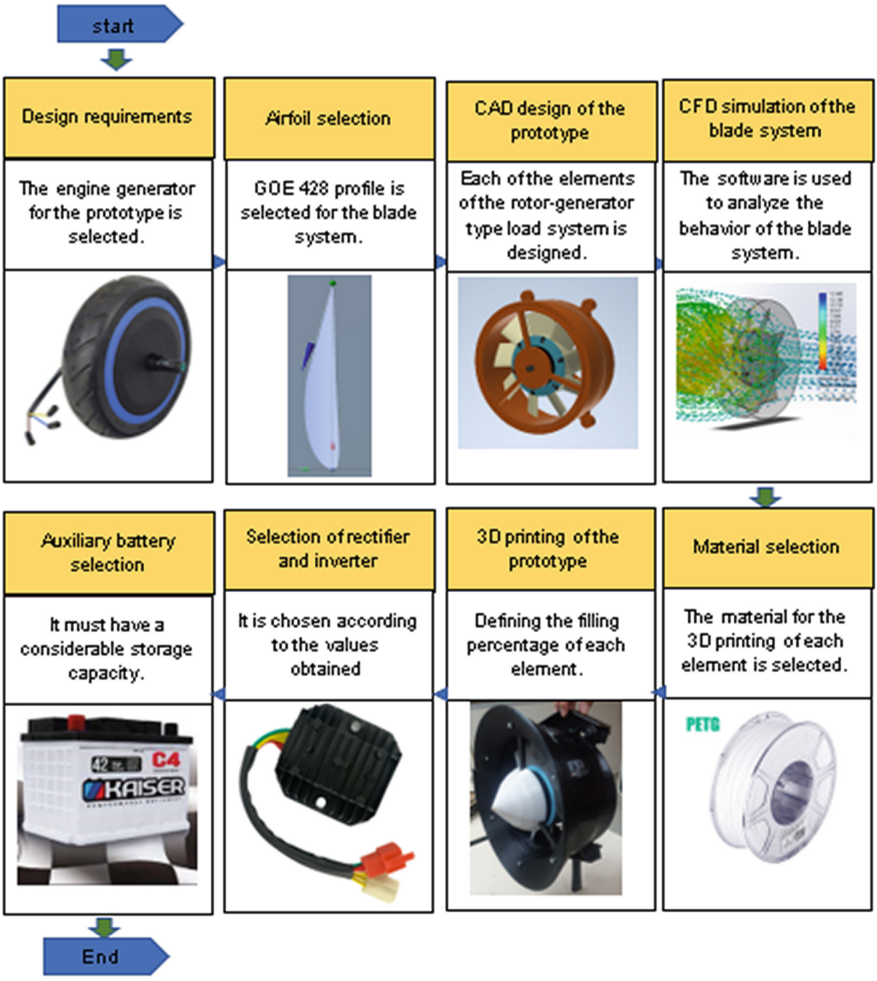

Fig. 1. Rotor-generator type load system design flowchart.

Design Considerations

The prototype to be developed must meet the following general characteristics for proper operation:

- Components must be made of lightweight, durable, commercially available materials that allow for proper fabrication and assembly.
- Avoid the use of mechanical transmission between the rotor and the generator to minimize energy conversion losses.
- The suitable construction of the prototype will allow field testing on the given route, easy to install and light, while providing rigidity, stability to counteract the effects of excessive vibration.

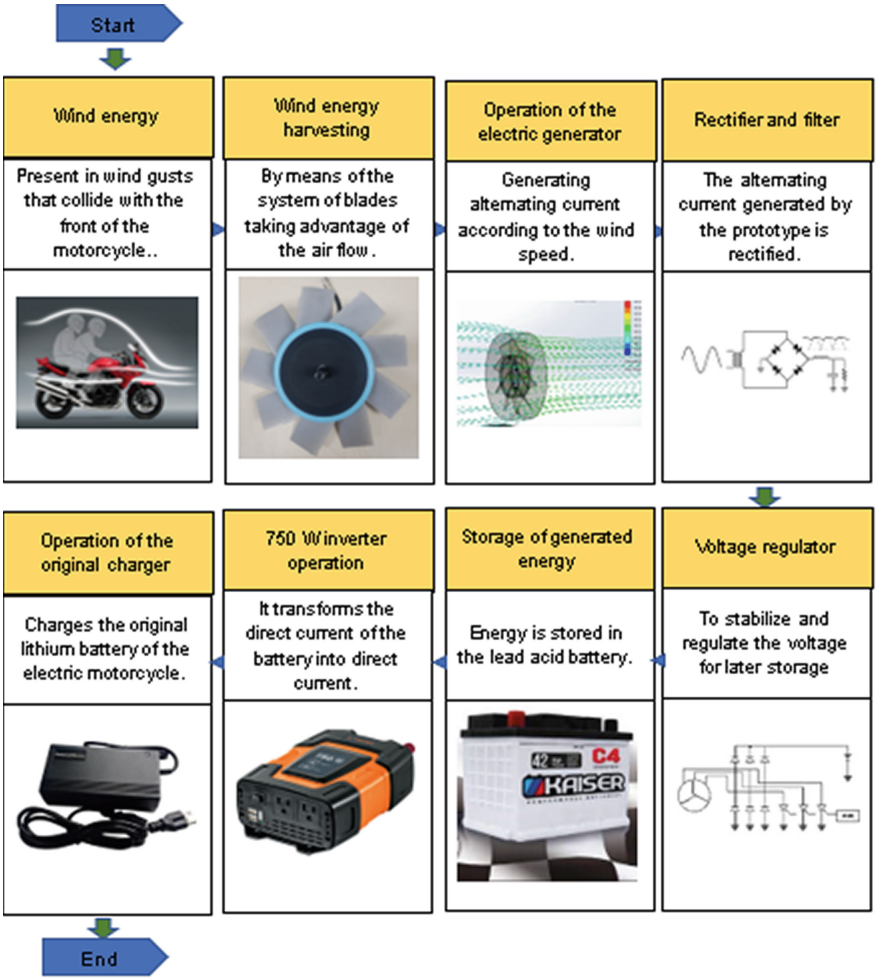

Fig. 2. Flow chart of operation of the rotor-generator type loading system.

– It should be easy to transport and position so that it can be installed on the front of the electric motorcycle.

Evaluation of Available Wind

In order to evaluate the feasibility of using wind as an energy source, it is necessary to know its characteristics, since wind is an unstable and uncertain resource, therefore, through the use of an anemometer we proceed to obtain the velocities at the site of the initial tests (Table 1).

Table 1. Tabulation of wind speeds

Motorcycle speed	Maximum air speed (m/s)
First Speed (40 to 45 km/h)	6,3
Second Speed (45 to 50 km/h)	12,9
Third Speed (50 to 60 km/h)	14,6

Nominal Wind Speed

The average wind speed obtained based on the use of the anemometer during the driving cycle is obtained by Eq. 1.

$$Vm = \frac{V_1 + V_2 + V_3}{3} \tag{1}$$

$$Vm = \frac{6.3 + 12,9 + 14,6}{3}$$

$$Vm = 11,26\,[\mathrm{m/s}]$$

$$Vn = 11\,[\mathrm{m/s}]$$

Air Density

To determine the aerodynamic coefficient, it is important to calculate the air density at the initial and final test locations using Eq. 2 and the time data from the Microsoft application in real time during test development.

$$\rho = \frac{0,34848p - 0,009h_T * (0,061t)}{273,15 + t} \tag{2}$$

$$\rho = \frac{0,34848(1026\mathrm{mbar}) - 0,009(0,59) * (0,061 * 13\,^{\circ}\mathrm{C})}{273,15 + 13^{\circ}C}$$

$$\rho = 1,2495\,[\mathrm{kg/m^3}]$$

Wind Force

When the wind hits the blade system, it generates a force determined by Eq. 3.

$$P\,viento = \frac{1}{2} * \rho * v^2 \tag{3}$$

$$P\,viento = \frac{1}{2} * 1,2495 * 11,26^2$$

$$P\,viento = 79,21\,[\mathrm{Pa}]$$

Centrifugal Force

The centrifugal force is due to the rotation of the blade system and is calculated by Eq. 4.

$$F_c = m * R * w^2 \tag{4}$$

$$F_c = 0.025\text{kg} * 0,05\,\text{m} * 180,16^2$$

$$F_c = 40[\text{N}]$$

$$w = \frac{\gamma * v}{R} \tag{5}$$

$$w = \frac{0,8 * 11,26}{0,05}$$

$$w = 180,16\,[\text{rad/s}]$$

Wind Flow Measurement

To measure the flow rate, the area (Eq. 6) of the prototype exposed to the gusts of wind is determined, and this result is multiplied by the average wind speed when the motorcycle is in operation to obtain the flow rate.

$$A = \pi * r^2 \tag{6}$$

$$A = \pi * (0,106)^2$$

$$A = 0,035\,[\text{m}^2]$$

With this, the wind flow can be determined in the prototype using Eq. 7.

$$Q = Vm * A \tag{7}$$

$$Q = 11,26\frac{\text{m}}{\text{s}} * 0,035\,\text{m}^2$$

$$Q = 0,39\,[\text{m}^3/\text{s}]$$

Blade Design

The blades are one of the most important components of the prototype, as they are responsible for capturing the kinetic energy of the wind. For this aerodynamic profile to be used is one of the most important design of the most important design aspects

to achieve optimal performance. Optimal performance. The blades convert the linear motion of the wind into a rotary motion into rotary motion and transmit it to the generator.

Aerodynamic Profile
The GOE 428 AIRFOIL airfoil was chosen because this type of airfoil is recommended for wind turbine applications such as this design. It is one of the most widely used airfoils in aerodynamics. This airfoil conforms to aerodynamic tests and therefore expresses its geometry in percentages that adapt to different blade thicknesses and widths in the XY plane (see Fig. 3).

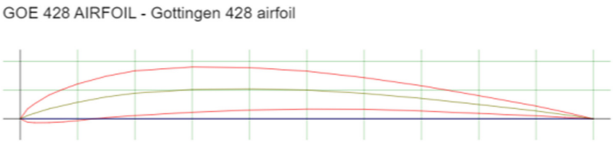

Fig. 3. GOE 428 profile selected for prototype

CAD Analysis of the Blade System
Through these analyses, it is possible to visualize the behavior of the blade system when exposed to constant air flows. The maximum and minimum speeds supported by the entire system are known and the location where the pressure exerted by the wind is concentrated is visualized.

Dynamic Analysis of the Blade System
This simulation allows visualization of the behavior of the blade system when exposed to an airflow at both the inlet and outlet. Nylon plastic material was chosen because it has similar characteristics to PETG material. This simulation observes the trajectories of the air flow to see where there is a higher concentration of flow, the inlet and outlet of the flow as it passes through the blade system, and the way the flow meets the entire system(see Fig. 4) (Fig. 5).

Analysis of the Prototype at Medium Speed
Due to the type of geometry of the prototype and the 9 blades that make up the whole system, the simulation shows that the largest amount of air is concentrated in the middle part, a rectilinear amount of air enters, hits the blade system and generates air distortion at the outlet. As a result, the geometry of the blades is optimal for the best capture of wind gusts (see Fig. 6) (Fig. 7).

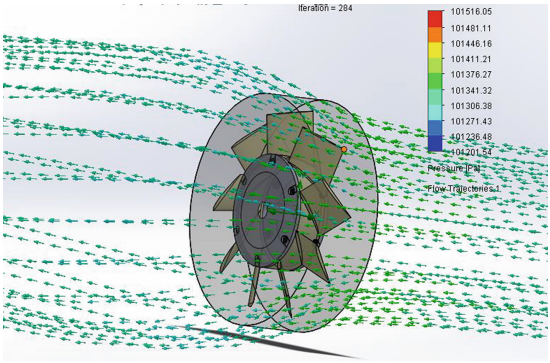

Fig. 4. Dynamic analysis of the blade system

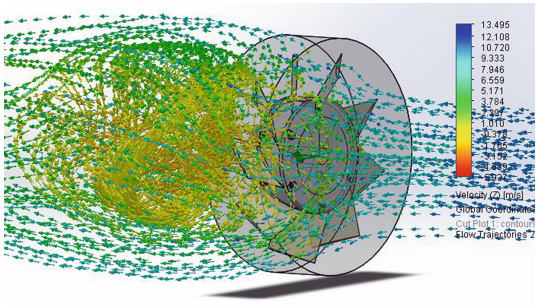

Fig. 5. Flow paths in the blade system

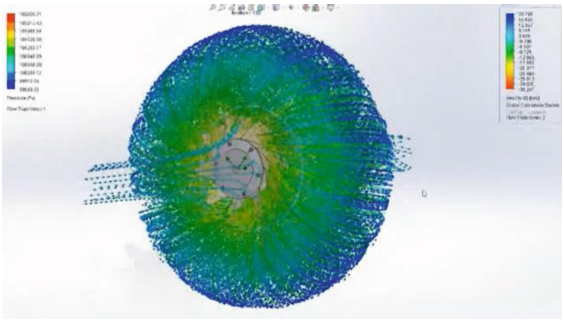

Fig. 6. Analysis of the blade system at an average speed of 11.24 m/s

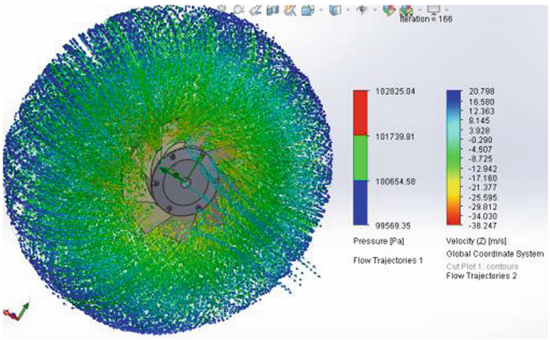

Fig. 7. Flow paths in the blade system at 11.24 m/s

1.2 Results and Discussion

Dynamic Analysis Results

The CFD simulation of the prototype at rest made it possible to visualize its operation and the speed values it reaches in a dynamic state. Table 2 shows results obtained from dynamic simulation.

Table 2. Results obtained from dynamic simulation

Variables to analyze	Values
Pressure	101201.54 [**Pa**]–101516.05 [**Pa**]
Speed	0.223 [m/s]–19.314 [m/s]
Temperature	293.14 °K–293.28 °K (19.99 °C–20.13 °C)
Air density	1.20 [kg/m^3]–1.21 [kg/m^3]
Reference pressure	101325.00 [Pa]

Results of the Analysis at Average Speed

By means of CFD simulation, when the prototype is exposed to an average speed of 11.24 m/s, it was possible to visualize its operation and the speed values it reaches during its operation (Table 3).

Table 3. Analysis results at an average speed

Variables to analyze	Values
Pressure	99569.35 [**Pa**]–102655.31 [**Pa**]
Speed	0.160 [m/s]–63.995 [m/s]
Temperature	293.03 °K–295.27 °K (19.88 °C–22.12 °C)
Air density	1.18 [kg/m^3]–1.22 [kg/m^3]
Reference pressure	101325.00 [Pa]

1.3 Conclusions

In this part of the research, the CFD simulation of the blade system was developed in the dynamic state of the vehicle and when exposed to an average wind speed, with which the value of pressures, minimum speeds and maximum speeds at which the prototype works were obtained. Next, a test protocol and a driving cycle were developed on the route defined within the university.

The reason for choosing Computational Fluid Dynamics (CFD) simulation is to obtain the behavior of the blade system during operation and also to visualize the flow paths at a given average velocity.

Within the CAD simulation software, the flow simulation tool was used to obtain results of pressures and speeds at which the blade system can operate, considering the type of fluid, the atmospheric pressure, and the wind force of 11.24 m/s when the electric motorcycle reaches an average speed. The CFD simulation of the prototype showed some aspects to consider regarding the importance of an optimal aerodynamic design of the blade system and its behavior when exposed to a given wind speed.

For the development of this prototype a CFD simulation was performed to visualize the behavior of the propeller system when exposed to a wind flow, also an optimal design of the entire prototype was performed to later manufacture them by 3D printing.

The blade system managed to generate an acceptable amount of current, operating in wind regimes higher than 5 m/s, which implies a good efficiency in power generation. The prototype has a better performance in straight tracks where high speeds can be reached and consequently a better efficiency in power generation.

CFD simulation was used from the conceptual phase of this project to determine the feasibility of the propeller system for the wind generator, and through this simulation it was determined that the shape of the propeller system was the most appropriate for proper use of wind energy.

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