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DESIGN OF THE ROTOR OF A SAVONIUS TYPE WIND TURBINE USING THE DIFFERENTIAL EVOLUTION ALGORITHM

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ABSTRACT
The present work describes the design of a vertical axis wind turbine type Savonius, to be applied in the generation of electrical energy taking advantage of the maximum power of the wind. First, the problem statement is carried out using classical optimization techniques, to generate the objective function to be minimized, as well as to establish the necessary restrictions in the calculation of the wind turbine measurements. Once the optimization problem was raised, the differential evolution algorithm was implemented to calculate the wind turbine measurements. Based on the rotor diameter and the overlap value, a design was generated in CAD software that allowed the analysis of the aerodynamics of the wind turbine rotor. The studies that were carried out are: wind speed analysis, flux density analysis and turbulence analysis. Finally the conclusions of this work are discussed.

Keywords: Savonius, Objective function, DEP Rules. Optimization, Differential Evolution, mutation, crossover.

INTRODUCTION:

Wind turbines.

To take advantage of the energy contained in the wind, a large number of wind machines have been developed according to the technology and techniques available at the time. However, it is possible to differentiate two types of machines based on the energy they deliver [1]:

- Mills. They transform the kinetic energy of the wind into mechanical energy, they are fundamentally for the pumping of water. They consist of a large number of blades (between 10 and 12), which allows them excellent operating conditions to lower wind speeds [1, pp. 1-18].
- Wind turbines. They transform the kinetic energy of the wind into electrical energy. In contrast to the previous ones, they are characterized by having few blades (between 1 and 3 generally) since in this way they reach to develop a greater efficiency in the transformation of energy [1, pp. 1-18].

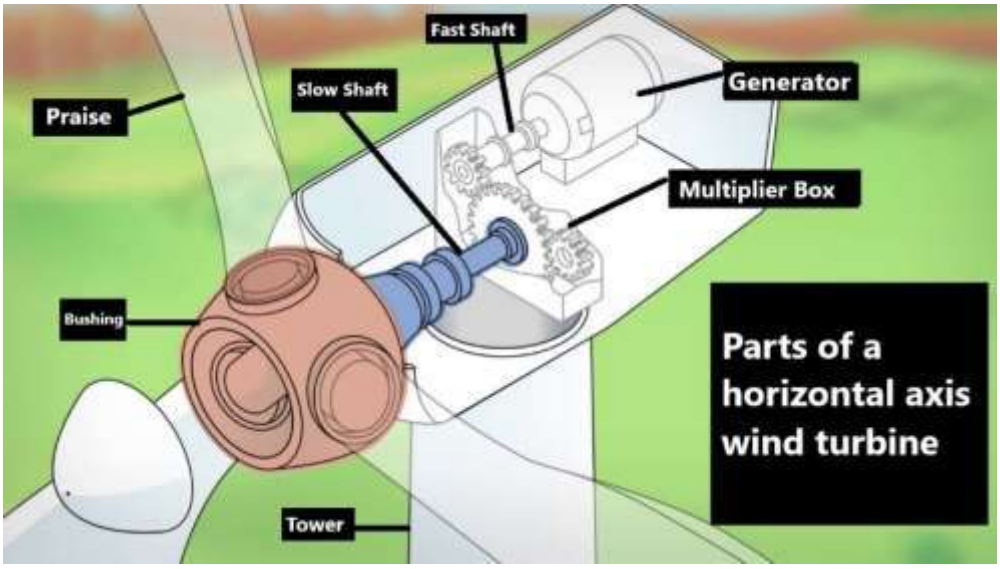

Figure 1 Components of a wind turbine [1].

Existing topologies

Wind turbines can be classified according to several criteria:

By its principle of operation:

- Based on drag: they have a small specific speed and a high starting torque.
- Based on lift: they have a higher specific speed, a lower starting torque and a higher energy production per unit area swept by the rotor [2, pp. 132-137].

By the arrangement of its axis of rotation:

- Horizontal axis: its axis of rotation is parallel to the direction of the wind.
- Vertical axis: its axis of rotation is perpendicular to the direction of the wind.

Other classifications:

- They can also be classified based on the specific speed () defined as the ratio of the linear wind speed of the blade (u) and the wind speed (v). The specific speed is also known as Tip Speed Ratio (TSR). According to this criterion they are classified into slow, intermediate and fast [2, pp. 132-137].
- They can also be classified according to their rotational speed: in rotors of constant speed and variable speed, or according to the power control system used, as passive control or aerodynamic loss (stall) and active control by variation of the pitch angle. [2, pp. 132-137]).

The size of the wind turbine is directly linked to the power it has. Therefore, a low-power generator will be considerably smaller than a high-powered on [2, pp. 132-137].

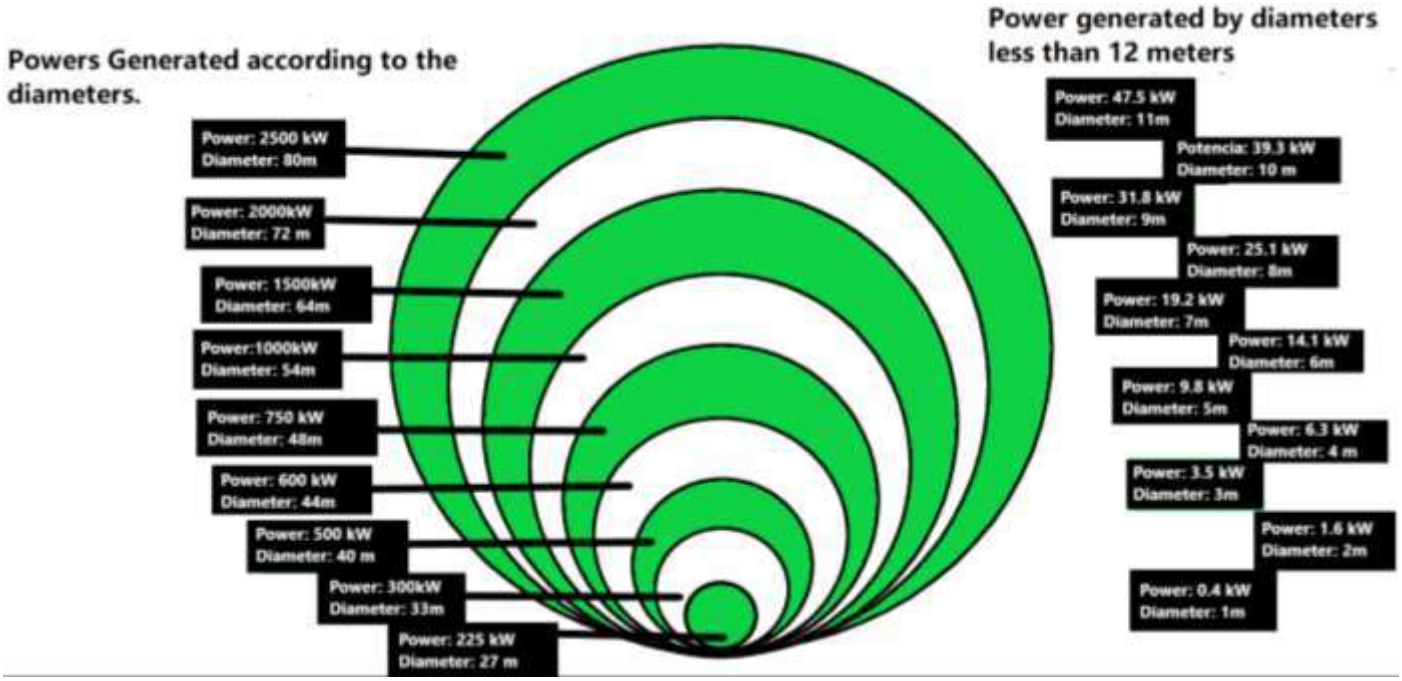

Figure 2 Relationship between blade diameter and power produced [2].

Vertical axis wind turbines.

As the name implies, in this type of wind turbine the axis of rotation of the rotor is located perpendicular to the direction of the wind, therefore, they work by the principle of drag. It has the advantage of not needing to orient itself with respect to the direction where the wind blows, efficiently taking advantage of the direct force of the wind without wasting part of it. Another advantage it has is that the generation and control equipment is located at the foot of the structure, at ground level, which simplifies and considerably cheapens maintenance operations [3, pp. 45-54].

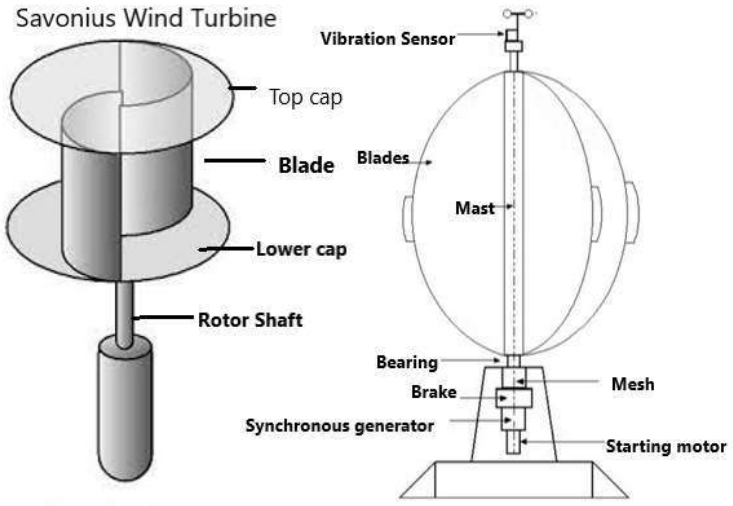

Figure 3 Vertical axis wind turbines type Darrieux and type Savonius [3].

Wind Turbine Savonius type:

The Savonius rotor was invented by the Finnish engineer Sigurd J. Savonius in 1922. His design is relatively simple and consists of two vertical blades with a curved profile. Viewed from above, the blades form an "S". This placement of the blades and their curvature causes a difference between the aerodynamic resistance of each blade, causing one of them to absorb the kinetic energy of the wind, while the other deflects the wind to the sides. The Savonius rotors basic

principle is propulsion by forces of drag ("drag"), since the blade that absorbs the wind kinetic energy is dragged (or pushed) by it. The blades can be placed with a spacing e (or overlap), which is an added parameter rotor design and can vary their behavior [4].

There are different wind turbine types of configurations of the Savonius rotor, the most common is that of two blades, but at the same way there are studies that prove the advantages and disadvantages of the configuration with three and four blades that show the power variation in their different configurations [5].

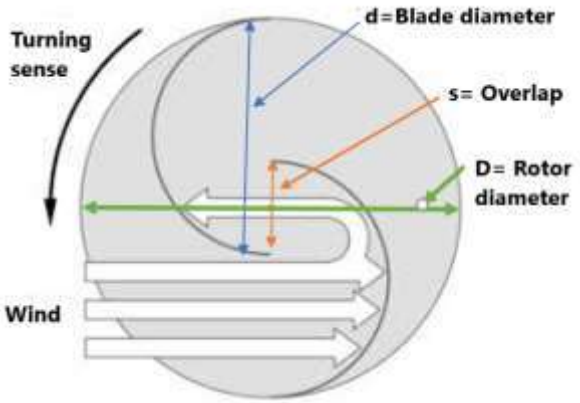

Figure 4 Principle of operation of the Savonius rotor [5].

METHOD:

Engineering optimization.

Optimization can be defined as the process to obtain the conditions that produce the maximum or minimum of the function's value. There is no method to efficiently solve all optimization problems. Optimization methods are also known as mathematical programming techniques and are often studied in operations research. Operations research is a mathematics branch that deals with methods and techniques applicable to decision-making problems, as well as the establishment of the best possible solutions (that is, the best ones) [6].

Statement of an optimization problem.

An optimization problem can be posed as follows:

$$\text{Find } X = \begin{Bmatrix} x_1 \\ \cdots \\ x_n \end{Bmatrix} \text{ that minimizes } f(x) \qquad (1)$$

Subject to:

$$g_j(x) \leq 0 \quad j = 1,2,\ldots,m \qquad (2)$$

$$h_j(x) = 0 \quad j = 1,2,\ldots,p \qquad (3)$$

Where X is the vector of the design variables, is the objective function, and are the constraints of inequality and equality, respectively. The problem thus posed is called, optimization problem with constraints [6, pp. 5-7].

Some optimization problems do not consider any kind of restrictions, so they are called, unrestricted optimization problems.

$$\text{Find } X = \begin{Bmatrix} x_1 \\ \cdots \\ x_n \end{Bmatrix} \text{ that minimizes } f(x) \qquad (1)$$

Mathematical model of the maximum power of the Savonius rotor.

The design of a Savonius rotor is based on the efficiency of the machine and the efficiency of the transmission so the maximum electrical power is given by the following expression:

$$P_{electr} = \eta_e \eta_t P_{aerog} = C_p \frac{1}{2} A \rho v^3 \eta_e \eta_t \qquad (4)$$

Where:

P_{electr}=Electrical power,

η_e=Efficiency of the electric machine,

η_t=Efficiency of mechanical transmission,
Cp=Power coefficient of the wind turbine,
ρ=Fluid density,
A=The area swept by the turbine,
v =Wind speed.
The next step is to calculate the sweep area, which is defined by the size of the wind turbine which comprises the total diameter of the rotor, and the length of the blade. It corresponds to the section of air that encloses the turbine in its movement and depends on the type of turbine to be designed. The sweep area is calculated as follows:

$$A = D * h \quad (5)$$

Where:
D= rotor diameter,
h= height of the blade.
Figure 5 shows one of the different designs that can be implemented in the design of vertical axis wind turbines type Savonius, since recently experiments have been carried out with different types of rotor design, especially in the configuration of the blades [7, pp. 117-125].

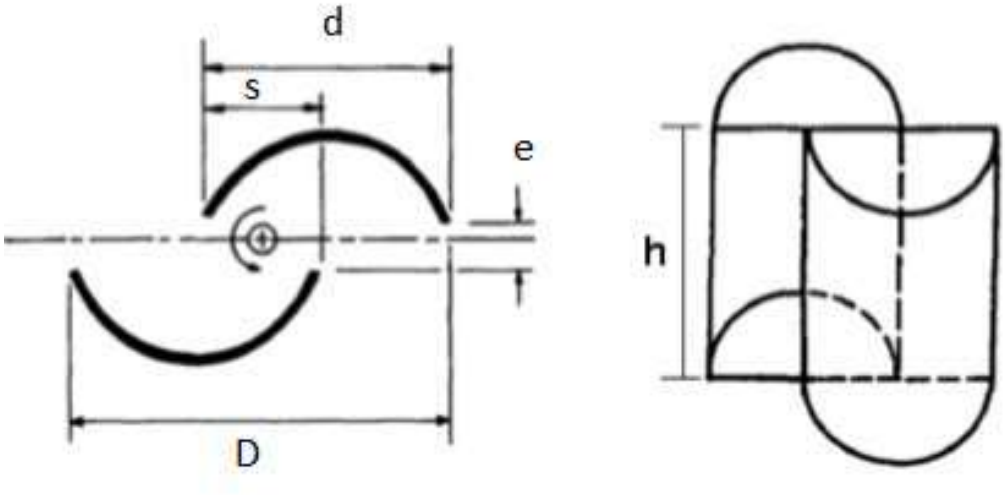

Figure 5 Design of the blades of the Savonius rotor [7].

Where:
e: Distance between blades.
s: Overlap.
h: Height or length of the blade,
d: Blade diameter,
D: Rotor diameter.
To determine the geometric parameters of the wind turbine developed, the following conditions will be considered: The recommendation made by Sandia Laboratories in the SAND76-0131 report is taken into account**,** in which it is mentioned that for the optimal design of a Savonius type wind turbine the s/D ratio goes between 0.1 to 0.15. Likewise, it must have an e = 0 and a ratio h / D = 2, considering what is stated by those who say that the distance between blades, e, must have a value of zero and the aspect ratio h / D must be greater than or equal to 2 to achieve an optimal design of a Savonius wind turbine. [8, pp. 19-21]
Substituting the value of the area in the $A = D * h$ electric power formula yields:

$$P_{electr} = \frac{1}{2} C_p h\, D \rho v^3 \eta_e \eta_t \quad (6)$$

P_{electr} = Electrical Power.
C_p = Aerodynamic coefficient.
h = Height.
v = Wind speed.
D = Rotor Diameter.
ρ = Wind density.

η_e = Machine efficiency
η_t = Transmission efficiency
For design purposes, certain parameters have been established that are considered as constants such as the aerodynamic coefficient and the wind density which have the following values:

$$Cp = 0.2$$

$$\rho = 0.889\ {}^{kg}/_{cm^3} \quad (7)$$

By substituting the values, the expression of the maximum electrical power can be simplified as follows:

$$P_{electr} = \frac{1}{2}(0.2)(0.889\ {}^{hg}/_{cm^3})h\ Dv^3\eta_e\eta_t$$

$$P_{electr} = 0.0889h\ Dv^3\eta_e\eta_t \quad (8)$$

To be able to calculate the height of the Savonius rotor you can use the ratio h / D = 2, which sandia Laboratories suggests in the report SAND76-0131**,** therefore, the height is given by : [8, pp. 19-21]

$$h = 2 * D \quad (9)$$

By replacing the height calculation in the power formula we can obtain:

$$P_{electr} = 0.0889(2D)\ Dv^3\eta_e\eta_t \quad \text{simplificando:}$$

$$P_{electr} = 0.1778D^2\ v^3\eta_e\eta_t \quad (10)$$

Figure 5 shows which are the parameters that have to be calculated in the design of the blades, and one of the main ones are; the diameter of the rotor, the diameter of the blades the value of the overlap, so the expression representing the calculation of the overlap is as follows:

$$D = 2d - s \quad (11)$$

Where:
s = Overlap
D = Rotor's diameter
d = Blade's diameter
With this expression you can make the substitution in the electric power formula being as follows:

$$P_{electr} = 0.1778(2d - s)^2\ v^3\eta_e\eta_t \quad (12)$$

As it is desired to obtain the optimal measurements of the design of the Savonius rotor, for a speed and efficiency parameters established we can say that for a v = 2.5 m / s and values of machine efficiency and an efficiency of the transmission of , the expression obtained is: $\eta_e = 0.82\eta_t = 0.83$

$$P_{electr} = 0.1778(2d - s)^2(2.5)^3(0.82)(0.83)$$

$$P_{electr} = 1.8907(2d - s)^2 \quad (13)$$

It can be observed that the maximum electrical power obtained is a function of the variables which are the diameter of the blade "d" and the value of the overlap "s".
The design of wind turbines has evolved over the years because it has always been about designing wind turbines that make the most of the power of the wind that is why several studies have been carried out on different forms of rotor configuration. [9]

Optimization approach.

Most of the wind turbines that are known, it is known that it is almost impossible to have 100% of the use of the force of the wind in the generation of electrical energy, due to various factors that affect that performance. Horizontal axis wind turbines are usually those with a higher aerodynamic coefficient, that is, a higher performance in the transformation of wind force into electrical energy. But however, vertical axis wind turbines do not have that advantage of taking advantage of the force of the wind.
Being able to obtain the highest power in a Savonius rotor means being able to generate a good amount of electrical energy, in order to be able to supply lighting in a building.
That is why for the optimal design of the wind turbine it is considered:

- The diameter of the blade and the value of the overlap.

Merit function for the maximum power generated.

As can be seen in the mathematical model obtained, the formula obtained at the end is the electrical power generated by the wind speed as a function of the diameter of the blade and the value of the overlap of the blades.
Let be the function defined as:

$$P_{electr} = 1.8907(2d - s)^2 \quad (13)$$

From where:

d = is the blade diameter
s = is the overlap value

Determination of restrictions

One of the considerations in the design of the Savonius rotor is to consider according to Sandia Laboratories in the SAND76-0131 report, that the value of the s/D ratio will be between the values of 0.1 to 0.15, but considering that the value of $D = 2d - s$.

Therefore, it can be said that:

$$0.1 \leq \frac{s}{D} \leq 0.15 \quad (14)$$

Substituting the value of $D = 2d - s$

$$0.1 \leq \frac{s}{2d-s} \leq 0.15 \quad (15)$$

Dimension of the diameter of the blades.

Whereas the Savonius rotor will be placed in a restricted area between 1 and 1.5 meters wide, it considers that the diameter of the blade should be restricted to the following values:

$$0.35 \leq d \leq 0.5 \quad (16)$$

Savonius rotor optimization problem

In order to establish an optimal design problem as an optimization problem, be the vector of design variables:

$$x = (x_1, x_2) = (d, s) \quad (17)$$

Therefore, the optimization problem for power generation is established as:

$$\underset{x \epsilon R^2}{\text{Max}} \quad P(x) = 1.8907(2x_1 - x_2)^2 \quad (18)$$

Subject to:

$$g_1(x) = -1.1x_2 + 0.2x_1 \leq 0 \quad (19)$$
$$g_2(x) = 1.15x_2 - 0.3x_1 \leq 0 \quad (20)$$
$$g_3(x_1, x_2) = 0.35 - x_1 \leq 0 \quad (21)$$
$$g_1(x_1, x_2) = x_1 - 0.5 \leq 0 \quad (22)$$

Once the optimization problem has been posed in conjunction with its design constraints, the programming of the differential evolution algorithm is carried out, [10, pp. 73-83]

The Differential Evolution Algorithm (ED)

Differential evolution is a branch of evolutionary computing developed by Rainer Storn and Kenneth Price, for optimization in continuous spaces.

In differential evolution (ED), variables are represented by real numbers. The initial population is randomly generated and three individuals are selected as parents. One parent is the primary parent and the parent is disturbed by the vector of the other two parents. If the resulting value is better than the one chosen for replacement, then replace it. Otherwise, the main parent is retained. [11, pp. 28-33]

Diagram of the differential evolution algorithm

ED is a search method that uses N vectors:

$$x_{i,G}; \ \ i = 0, 1, 2, \ldots, N - 1 \quad (23)$$

As the population of each generation (G). the value of N does not change during the minimization process. The initial population is chosen randomly if nothing is known about the problem. As a rule, a uniform distribution is assumed for the random decisions to be made. The main idea behind ED is a new scheme for generating vectors. ED generates these new vectors when the difference in weights between two population member vectors is added to a third member vector. If the suitability of the resulting vector is less than the chosen population member then the new vector replaces the vector with which it was compared. This vector to be compared may be (although it is not necessarily) part of the generation process mentioned above. In addition, the best vector is evaluated in each generation G so as not to lose sight of the progress during which minimization is made [11, pp. 28-33].

Implementation of the algorithm in the design of the wind turbine.

There are different versions of the differential evolution algorithm, in the particular case of the optimization problem raised above, the version known as ED/rand/1/bin was implemented, whose pseudocode is shown in the following figure. In the pseudocode shown the breakdown of how the population is initialized is seen, as well as the process of mutation and crossing [12, pp. 37-41],

Pseudo-code for DE/rand/1/bin
Begin
Randomly generate the initial population of vectors in the D-dimensional search space
Evaluate the initial population
Repeat
For $i = 1$ **until** NP **do**
Randomly select $r_0 \neq r_1 \neq r_2 \neq i$
$J_{rand} = rand[1, D]$
For $j = 1$ **until** D **do**
If $(rand_j[0,1] < CR)\boldsymbol{or}(j = J_{rand})$ **them**
$u_{j,i,g+1} = x_{j,r0,g} + F\left(x_{j,r1,g} - x_{j,r2,g}\right)$
Else
$u_{j,i,g+1} = x_{j,i,g}$
End if
End for
If $\left(\boldsymbol{f}\left(\vec{\boldsymbol{u}}_{\boldsymbol{i,g+1}}\right) \leq \left(\boldsymbol{f}\left(\vec{\boldsymbol{x}}_{\boldsymbol{i,g}}\right)\right)\right)$ **them**
$x_{i,g+1} = u_{i,g+1}$
Else
$x_{i,g+1} = x_{i,g}$
End if
End for
G=G+1
Until a termination conditions are met
Fin

Figure 6 Pseudocode of the differential evolution algorithm used [12].

In order to make the optimal selection of the solution of the problem it was proposed to use a constraint handler called Deb Feasibility Rules. these rules use the box called SVR (sum of violation of restrictions), which is responsible for the selection between the father and the child, under the following criteria:

- Between two feasible solutions, the one with the best value of the merit function is selected.
- Between a feasible and a non-feasible solution, the feasible one is selected.
- Between two non-feasible solutions, the one with the lowest sum of violation of restrictions is selected. The sum of violation of constraints is calculated with the following formula:

$$\text{SVR} = \sum_{i=1}^{p} \max\left(0, g_i(x)\right) + \sum_{j=1}^{q} \max\left(0, \left|h_j(x)\right|\right) \quad (38)$$

The computational implementation would be as follows:

$$\text{SVR} = \sum_{i=1}^{p} \max\left(0, g_i(x)\right) + \sum_{j=1}^{q} \begin{cases} 0 & h_j(x) \leq \varepsilon \\ \left|h_j(x)\right| & |h_j(x)| > \varepsilon \end{cases} \quad (39)$$

Where ε is the slack or vicinity of zero for equality restrictions.
The differential evolution algorithm already with the implementation of the DEP feasibility rules is shown in the following figure.

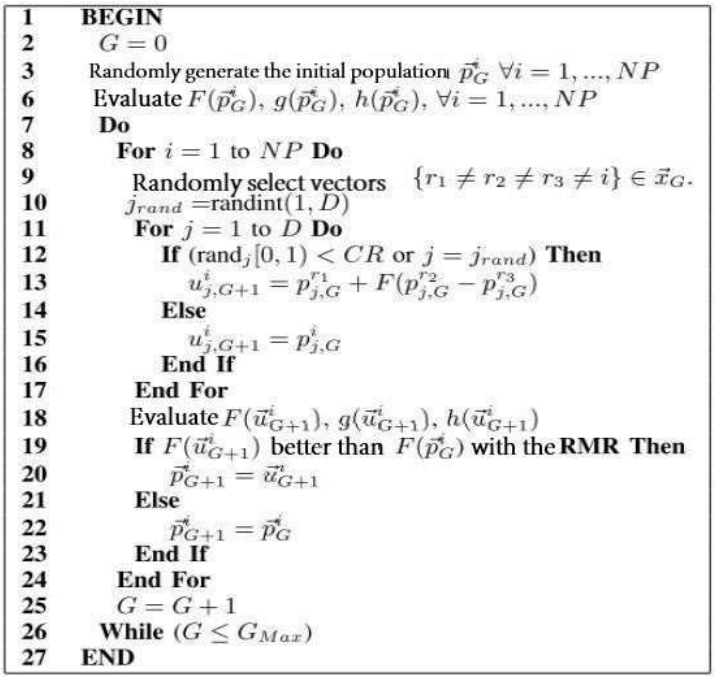

Figure 7 Differential evolution algorithm with constraint handling [13].

The algorithm was implemented in MATLAB and in order to obtain the optimal design of the wind turbine, it was executed 30 times, in order to observe the behavior in solving the problem. Because a random CR cross factor was used, as well as an equally random scaling factor F, a table was created with the best individuals created by the algorithm in the 30 executions. [13]

Table 1 Data obtained in the execution of the algorithm.

Runs made with the algorithm					
	Diameter	Overlap	Objective function	Crossover factor	Scaling Factor
Run number	x1	x2	F.O.	CR	F
1	0.497678	0.106124	1.495040	0.659155	0.727242
2	0.499671	0.101212	1.525113	0.592247	0.672551
3	0.499445	0.100089	1.527393	0.511685	0.403212
4	0.497583	0.109666	1.482518	0.847475	0.440001
5	0.499480	0.100628	1.525795	0.677813	0.399944
6	0.488341	0.103177	1.442626	0.582464	0.449151
7	0.497189	0.101434	1.507552	0.754103	0.877278
8	0.491933	0.116526	1.422335	0.547557	0.359199
9	0.444913	0.103902	1.167842	0.657535	0.741702
10	0.499437	0.105262	1.509806	0.545263	0.727486
11	0.496331	0.106679	1.484133	0.657858	0.537152
12	0.493976	0.104658	1.475140	0.788627	0.626554
13	0.488806	0.104853	1.440161	0.791817	0.655067
14	0.473513	0.114313	1.311034	0.771505	0.455056
15	0.499506	0.111278	1.490010	0.843824	0.437655

16	0.497278	0.105713	1.493733	0.856073	0.316560
17	0.488535	0.107867	1.428451	0.852066	0.424199
18	0.497286	0.113161	1.468860	0.880368	0.617274
19	0.498004	0.104324	1.503300	0.606070	0.359817
20	0.498126	0.100535	1.516928	0.534168	0.350905
21	0.499755	0.101479	1.524773	0.677836	0.322187
22	0.494894	0.102101	1.489851	0.589519	0.502285
23	0.490082	0.105894	1.445152	0.515694	0.855825
24	0.499682	0.101126	1.525481	0.877136	0.817056
25	0.499470	0.102071	1.520829	0.565771	0.676293
26	0.499015	0.111539	1.485840	0.862628	0.403823
27	0.489982	0.102051	1.457221	0.563007	0.769590
28	0.498614	0.106429	1.500313	0.692321	0.733921
29	0.498978	0.103344	1.513184	0.613947	0.367085
30	0.492525	0.101915	1.474613	0.538066	0.542407

Table 1 shows the values of the design variables which with the diameter of the blade "d" and the value of the overlap "s", as well as the value of the merit function that in this case is the calculation of the maximum power generated by the rotor of the wind turbine, the values of the cross factor and the value of the scaling factor are also listed. Table 2 shows the best individual obtained in the 30 executions.

Table 2 Ordering of individuals according to which obtained the best objective function value.

Best individual					
	Diameter	Overlap	Objective function	Crossover Factor	Scaling Factor
Run number	x1	x2	F.O.	CR	F
3	0.499445	0.100089	1.527393	0.511685	0.403212
5	0.49948	0.100628	1.525795	0.677813	0.399944
24	0.499682	0.101126	1.525481	0.877136	0.817056
2	0.499671	0.101212	1.525113	0.592247	0.672551
21	0.499755	0.101479	1.524773	0.677836	0.322187
25	0.49947	0.102071	1.520829	0.565771	0.676293
20	0.498126	0.100535	1.516928	0.534168	0.350905
29	0.498978	0.103344	1.513184	0.613947	0.367085
10	0.499437	0.105262	1.509806	0.545263	0.727486
7	0.497189	0.101434	1.507552	0.754103	0.877278
19	0.498004	0.104324	1.5033	0.60607	0.359817
28	0.498614	0.106429	1.500313	0.692321	0.733921
1	0.497678	0.106124	1.49504	0.659155	0.727242
16	0.497278	0.105713	1.493733	0.856073	0.31656
15	0.499506	0.111278	1.49001	0.843824	0.437655
22	0.494894	0.102101	1.489851	0.589519	0.502285

26	0.499015	0.111539	1.48584	0.862628	0.403823
11	0.496331	0.106679	1.484133	0.657858	0.537152
4	0.497583	0.109666	1.482518	0.847475	0.440001
12	0.493976	0.104658	1.47514	0.788627	0.626554
30	0.492525	0.101915	1.474613	0.538066	0.542407
18	0.497286	0.113161	1.46886	0.880368	0.617274
27	0.489982	0.102051	1.457221	0.563007	0.76959
23	0.490082	0.105894	1.445152	0.515694	0.855825
6	0.488341	0.103177	1.442626	0.582464	0.449151
13	0.488806	0.104853	1.440161	0.791817	0.655067
17	0.488535	0.107867	1.428451	0.852066	0.424199
8	0.491933	0.116526	1.422335	0.547557	0.359199
14	0.473513	0.114313	1.311034	0.771505	0.455056
9	0.444913	0.103902	1.167842	0.657535	0.741702

In which it is observed that the best individual is the one obtained in run 3 since it is the one that has the best value of the objective function, which has the following values:

$$d = x_1 = 0.499445 \text{ m}$$
$$s = x_2 = 0.100089 \text{ m}$$

With these values we can calculate the power with the formula obtained above.

$$P_{electr} = 1.8907(2d - s)^2 \quad (40)$$
$$P_{electr} = 1.8907(2(0.499445) - 0.100089)^2 = 1.527389 \text{ watts.}$$

Also with the values obtained from diameter and overlap you can calculate the other design values of the wind turbine which are calculated below:
Calculating the height value:

$$h = 2 * D \quad (41)$$

from which it is known that:

$$D = 2d - s = \quad 2(0.499445) - 0.100089 \; = \; 0.898801$$

Therefore, the height value is calculated as follows:

$$h = 2 * (2d - s) \quad (42)$$

Substituting the corresponding values:

$$h = 2 * (2(0.499445) - 0.100089) \; = \quad 1.797602\text{m.}$$

Diameter of the lids:

$$d_t = 1.1 * D \; = \; 1.1\,(.898801) = .9886811\text{m}$$

RESULTS

Analysis of the results.

Another wind turbine was designed with the measurements calculated analytically to which the same studies were applied, which were applied to the wind turbine designed with the differential evolution algorithm, these studies are:

- Analysis of wind speed in the blades.
- Analysis of air flow density.
- Analysis of the intensity of turbulence.
- Analysis of turbulence dissipation.

In this chapter, images obtained from the software are presented in which the vectors obtained in the corresponding simulations are detailed, 4 images are presented, of which the first two with the initial design and the following are of the already optimized design. The aerodynamic analysis of the rotor is carried out based on the measurements obtained with the differential evolution algorithm [14, pp. 223-231]

Analysis of wind speed.

Design by Mr. Omar Chávez Cano.

The design presented in figure 11 and 12 was designed according to the averages obtained by Mr. Omar Chávez Cano, which is simulated with a maximum speed of 2.5 m / s, it can be seen in the images that the wind turbine does not have many critical areas, the bar that is on the left side at the top of the image shows that the critical area that the wind turbine has is between the value of 1.652 and 1.213, these values are shown at the exit of the rotor which are the green arrows. [15, pp. 27-33]

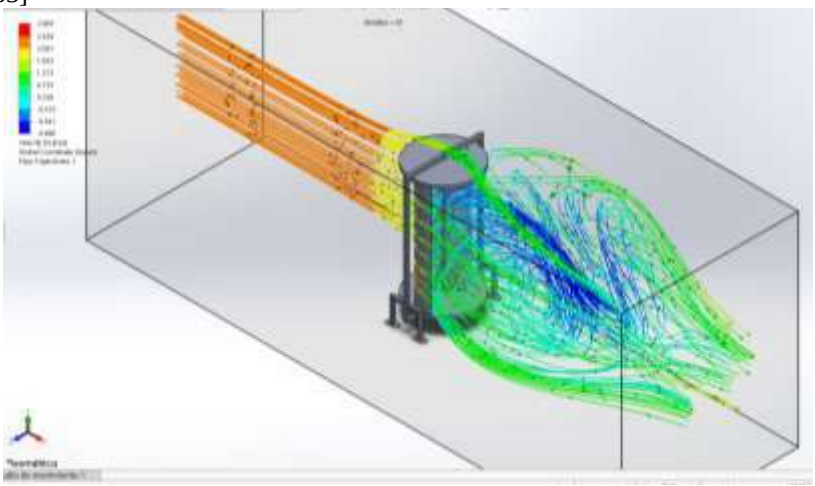

Figure 8 Isometric view of the wind turbine.

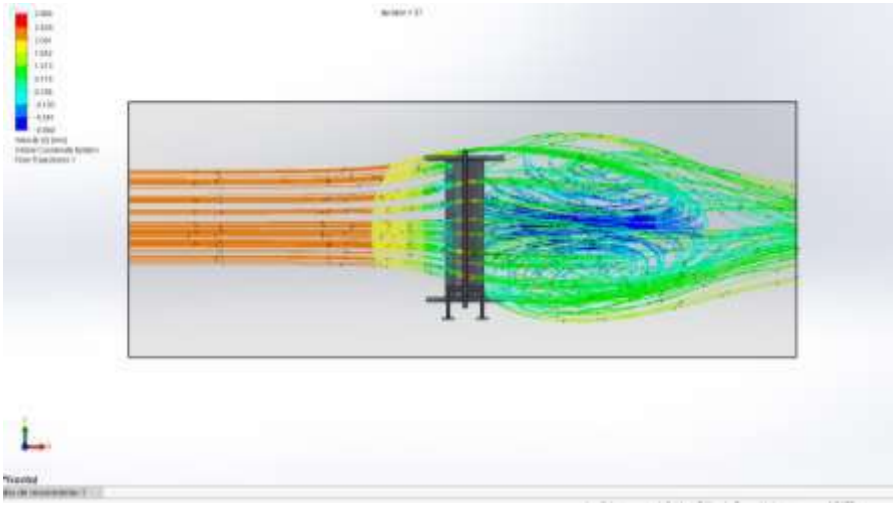

Figure 9 Side view.

The images presented below show the analyses carried out with the CAD software regarding the aerodynamics of the wind turbine, some of the studies show the maximum and minimum working values of the rotor based on [16, pp. 2048-2054]

Optimized design

Applying the differential evolution algorithm, the design of the initial wind turbine was optimized, with the measurements obtained it was possible to design in SolidWorks a wind turbine that has different characteristics in terms of the averages, since greater measures were obtained than those of the previous design.

In the images on the analysis of wind speed, the comparison between the Optimized design and the design made in a conventional way, show us that according to the color graph shown in figure 13, the lines of the optimized design are more within the acceptable values since as we can see it does not have much green coloration.

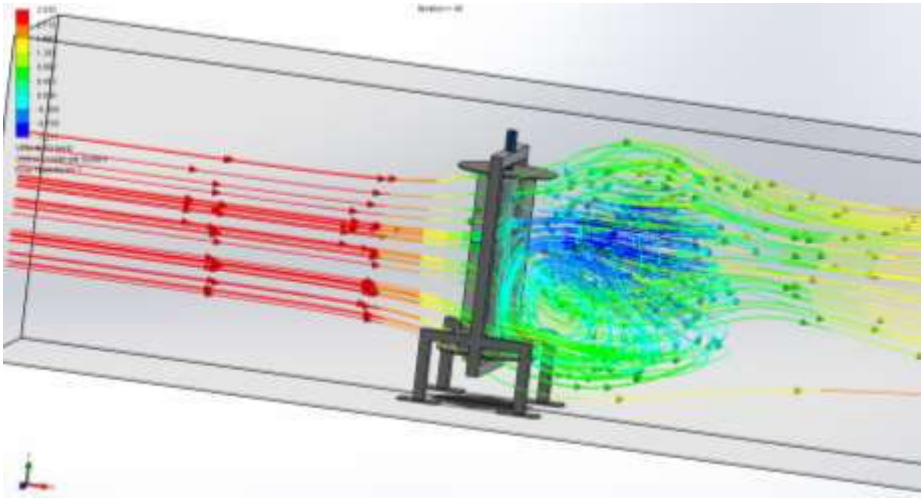

Figure 10 Isometric view of the optimized wind turbine.

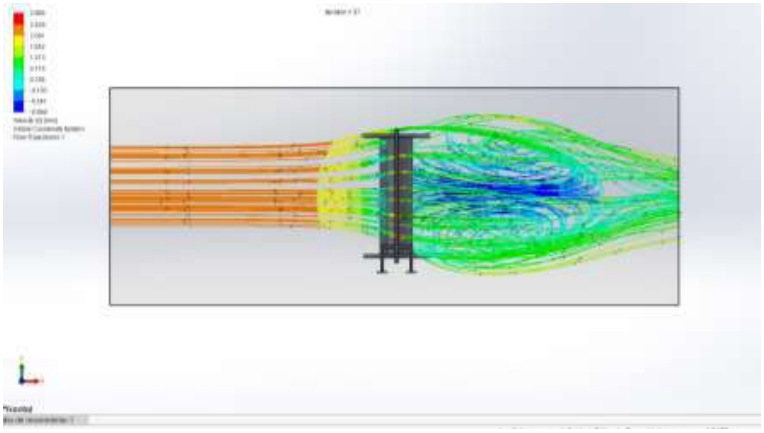

Figure 11 view of the non-optimized wind turbine.

As you can see in the images above it can be said that the optimized design takes more advantage of the wind speed since it does not have many losses in terms of wind speed.

Analysis of the flow density of wind turbines.

Design by Mr. Omar Chávez Cano

In this section the behavior of the flow density of the air is shown that as can be seen in the same way in the upper left corner the bar shows us what would be the critical values for the first design made, in this graph we can notice that according to the color it could be said that it has a slightly high flow density, although it does not present much turbulence.

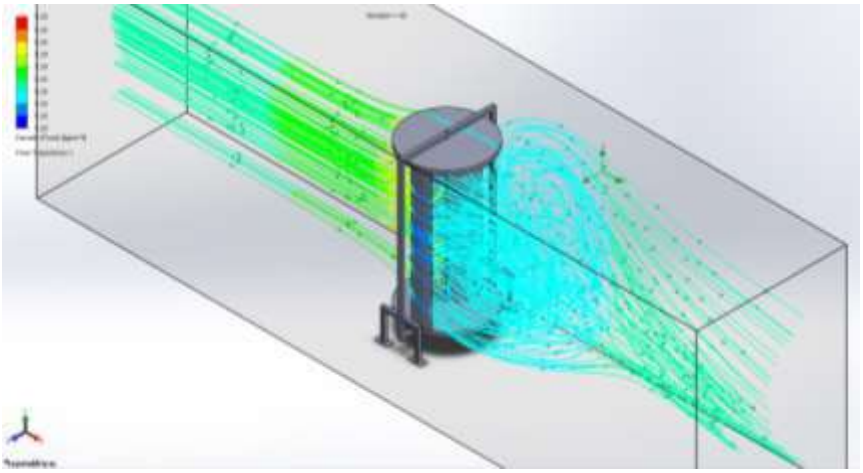

Figure 12 Isometric view of the wind turbine.

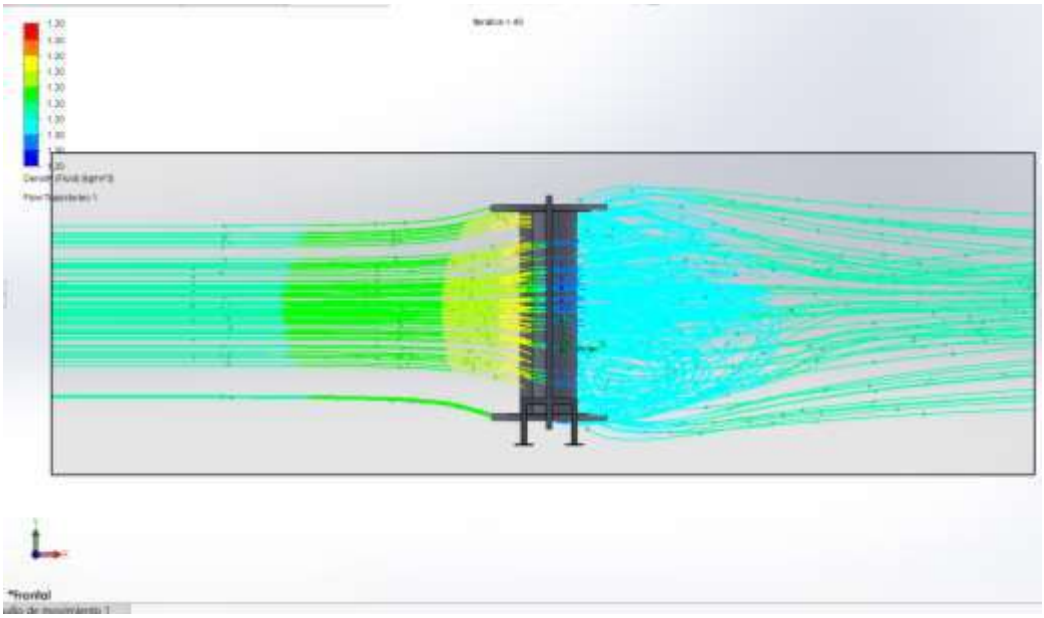

Figure 13 side view of the wind turbine.

Optimized design

Applying the analysis of the flux density it can be seen that in images 17 and 18 the design of the optimal wind turbine presents a better flux density since with respect to the color graph shown in the upper left corner of the images, the blue lines show us that the flow density is lower in optimal design than in the conventional design.

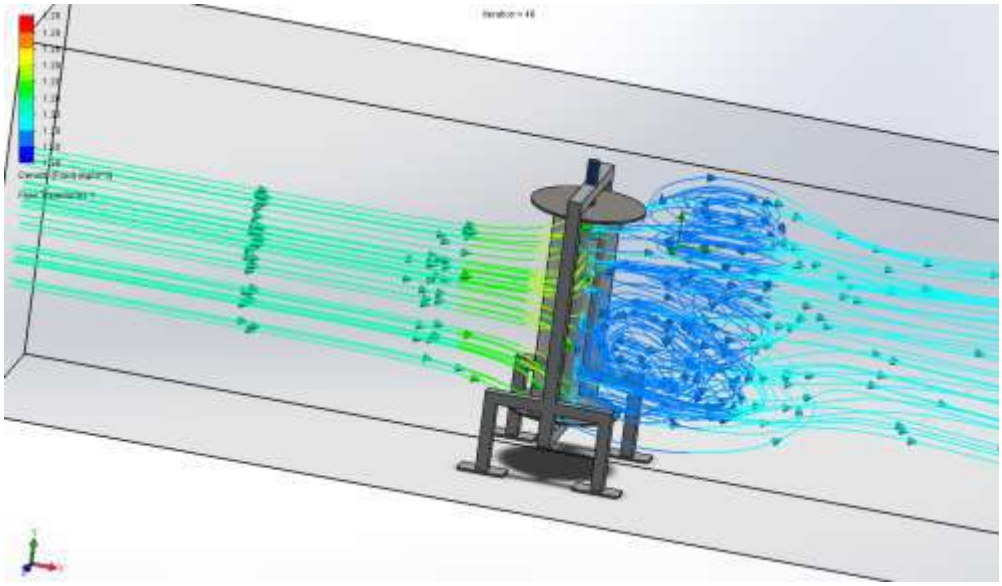

Figure 14 Isometric view of the optimized wind turbine.

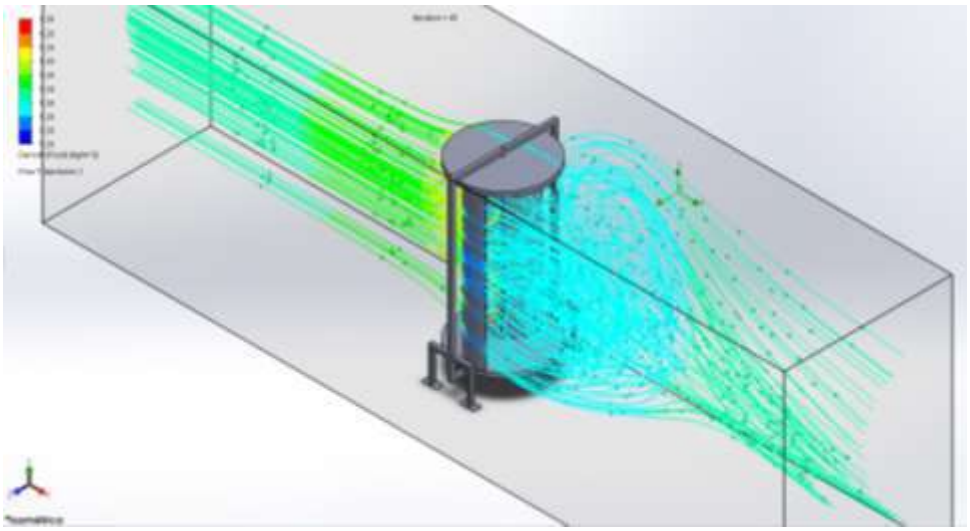

Figure 15 Isometric view of the conventional wind turbine.

Wind turbine turbulence analysis

In the following figure it is shown how is the analysis of the turbulence of the two designs of wind turbines, we can observe that one of the disadvantages that we can have in the wind turbine that was optimized is that it generates a lot of turbulence since the two rotors interfere with each other, but more nevertheless that conflict can be solved by performing an analysis to be able to obtain the optimal distance between each rotor and thus be able to reduce said interference.

Broadly speaking, none of the wind turbines have critical levels of turbulence.

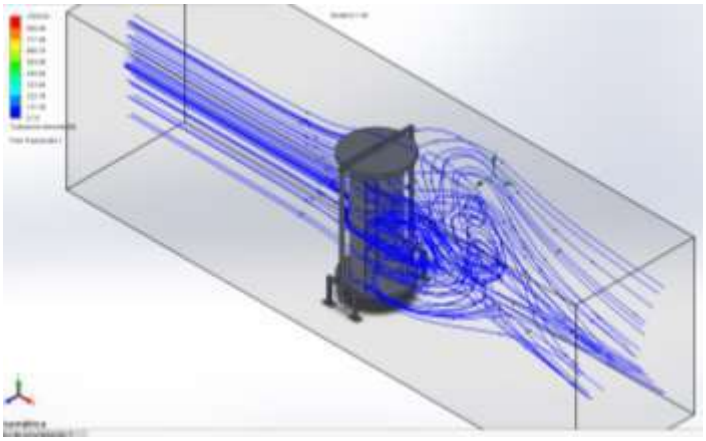

Figure 16 Isometric view of the conventional wind turbine.

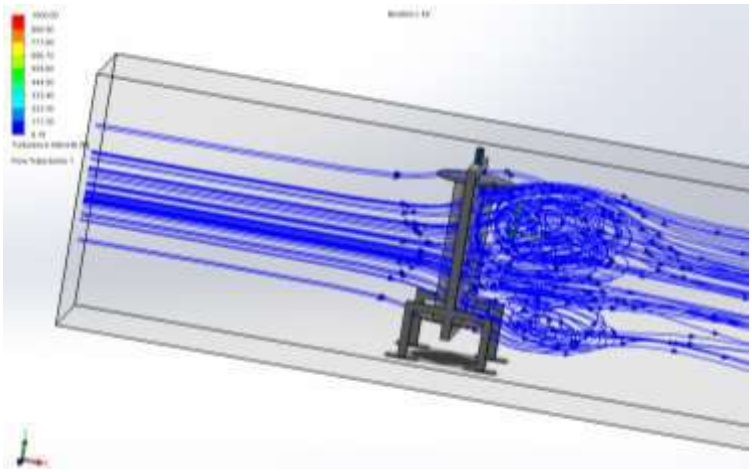

Figure 2017 Isometric view of the conventional wind turbine.

CONCLUSIÓN

Based on the designs obtained in this work, it can be said that the performance of the wind turbine improved in the use of wind speed, with respect to the previous model, going from generating a power of 0.472 Watts to 1.527389 Watts so it considerably increased the production of electrical energy.

If it is considered that the wind turbine could be implemented in the lighting of a building or common areas, the ideal is to place a set of wind turbines so that adding the power of these can supply the amount of energy needed, coupled with this should also be considered adding to the rotor shaft a speed multiplier this would considerably increase the production of electrical energy.

In the future it is considered to make modifications to the optimized design, such as including the speed variation in the differential evolution algorithm, placing a range of values in which the wind turbine could work, this could give a guideline to generate optimized design measures based on the speed ranges.

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