*International Journal of Engineering &Technology*, 7 (4) (2018) 6848-6850

International Journal of Engineering & Technology

*Website: www.sciencepubco.com/index.php/IJET*
*doi: 10.14419/ijet.v7i4.26843*
***Research paper***

# Design of a hydrokinetic turbine capable of satisfying electricity demand for housing on the margin of the Magdalena river through analysis by finite elements

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**Abstract**

This research is aimed to design a hydrokinetic turbine for electric generation taking advantage of available energy of the Magdalena River, which has a great flow near to its mouth in the Atlantic Ocean of Northern Colombian. The turbine design consists of a tri-bladed horizontal axis turbine totally submerged; the rotor is fixed to a metallic platform with tanks acting as floats. It also contains an asynchronous electric engine as a generator and electrical lines. The turbine power shaft is transmitted to the engine by a system of toothed belts, which performs the role of gearbox and multiplier. As a result, CFD simulations shows several variables of interest in order to evaluate power generation, such as torque, angular velocity, power, turbine efficiency, and hydrokinetic and structural analysis are obtained by means of finite elements.

***Keywords***: *Hydrokinetic Turbine; CFD Modelling; Wind Energy; Finite Elements.*

## 1. Introduction

Among others, a general social problem facing the Colombian Caribbean region is the low quality of life of people who are not connected to the electric network; causing isolation, limited cultural growth, and little technological development. In spite of government authorities have improved and spread the electric grid, there are many areas in which efforts have not been enough to satisfy all people needs, especially in rural areas. However, a great source of renewable energy is available, around Magdalena River where the proper technology can be used to solve, or at least, mitigate this problem.

Design a low-cost horizontal axis hydrokinetic turbine, which would be able to meet the energy demand of a house on the left shore of the Magdalena River in a rural area of North Colombia, is the objective of this study. Conducted field visits, studies of the environment in which the turbine was expected to work and bibliographic reviews of similar projects have been carried out, in order to simulate the dynamic behavior of the turbine in real conditions. [1] They did a CFD (Computational Fluid Dynamics) analysis to Savonius hydrokinetic turbine to harness energy from a stream of a tributary. [2] They analyzed the effects on the performance of the interaction in a hydrokinetic diffuser when comparing a naked turbine, with diffuser and with variation in the shape of a diffuser using CFD analysis. Obtaining, as a result, the importance of improving the performance of a turbine when is using a diffuser through better designs. [3] They performed analyzes using CFD techniques and proposed blocking corrections for axial and crossflow hydrocyclic turbines, and they calculate drag, power and velocity estimations. [4] They developed an approach using dynamics equation, taking into account the turbine blades to determine power coefficients, coupled to the transmission system, including the multiplier and the electric generator. Validating the results obtained by means of numerical simulation. [5] Simulated in a transient state to characterize a single turbine and multiple turbines, in one row and in staggering using the k-ω shear stress transport turbulence model (SST). In their results, they indicated that a power coefficient of 0.43 would be generated at its highest efficiency point.

## 2. Methods

### 2.1. Average electric energy consumption

The average energy consumption of low-income families located on the banks of the Magdalena River in a rural area is determined. Site surveys showed estimates the electric energy needs of families in order to design a model of hydrokinetic turbine that could provide a solution to the problem of lack of energy.

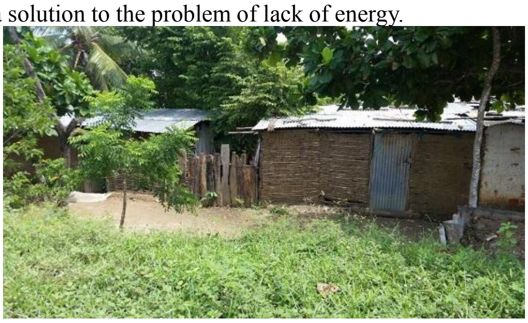

**Fig. 1:** Common Housing in Poor Families.

Some electric elements and devices that could be necessary to power in a low-income family are presented in Table 1.

**Table 1:** Required Electric Power of A Common Housing

| Elements or Devices | # | Hours | Power (W) | Daily Energy Consumption (Wh/day) |
|---|---|---|---|---|
| Light Bulbs | 3 | 6 | 60 | 1080 |
| Fan | 2 | 8 | 70 | 1120 |
| Radio | 1 | 3 | 15 | 45 |
| TV | 1 | 6 | 90 | 540 |
| Total | | 425 W | | |

A hydrokinetic turbine with an output of 425 W could meet the electric demand of a common housing that need approximately 2975kWh/day.

## 2.2. Hydrokinetic turbine design

Characterize the behavior of the river near to target housing, allow establishing the basic design needs and select, from different turbine models, those that can provide the electric supply needed, and can be built easily and without expensive initial investments. Table 2 shows dimensional parameters taken into account for the design of the turbine.

**Table 2:** Dimensions of the Hydrokinetic Turbine

| Parameter | Value |
|---|---|
| Turbine Output (W) | 425 |
| River average velocity (m/s) | 0.95 |
| Turbine Dimensions (m) | Length 2 - 3<br>Width 1.5 - 2<br>Height 1.2 – 1.6 |
| River density (kg/m$^3$) | 955.3 |
| Betz (%) | 0.45 (45) |
| Alternator (%) | 0.95 (95) |
| Transmission (%) | 0.98 (98) |
| Rotor Area (m$^2$) | 2.71230863 |
| Rotor Diameter (m) | 1.77 |
| Rotor Radio (m) | 0.89 |

A bent, curved and twisted bladed rotor has been selected as the main component of the hydrokinetic turbine with Tip Speed Ratio (TSP) λ_0 from 4 to 6. These ranges indicate that a type of generator that uses 2 to 3 blades can be implemented. Therefore the rotor will consist of three blades with spacing between blades at 120 ° to have a balanced system since a three-bladed wheel operates more smoothly than the designs of two blades, which have problems with balance and vibration as it increases the load. That is why the value of λ0 or TSR will have to be between 4 and 6. Analyzing Fig. 2. It is concluded that the celerity value for which the power coefficient is maximum is λ0 or TSR = 4.4.

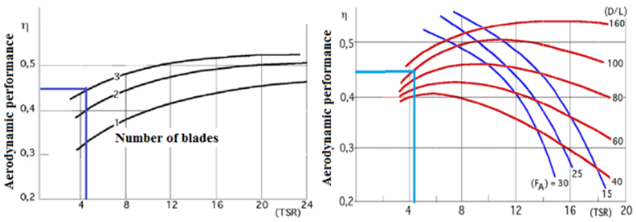


**Fig. 2:** Aerodynamic Performance (Haero), The TSR and the Number of Blades [6].

It is observed in Fig. 2 that the greater the number of blades, the greater the power coefficient, although the differences disappear when the speed acquires high values. For the chosen value (λ0 or TSR = 4.4), however, there are differences in the η aero performance. For a value of ηaero = 0.4, the D / L ratio will have an approximate value of 97. Based on the selected parameters there are a series of blade profiles that meet all the requirements. Among them are the following: NACA 0012, NACA 0015, NACA 4412, NACA 23000 (symmetrical), NACA 23018.

## 2.3. Material of the selected blade

E-type fiberglass was chosen as the material of the blade due a lighter and more resistant material was needed without sacrificing the manufacturing price, fiberglass, especially type E, because of the commercial resin used to mold it, this can take almost any figure, being quite light, which prevents the flow from having problems in overcoming the inertia of the propeller and can move it easily.

**Table 3:** Fiberglass Type E Properties

| Fiberglass type E | |
|---|---|
| Modulus of Elasticity (GPa) | 74.4 |
| Yield Strength (MPa) | 135 |
| Ultimate Strength (MPa) | 170 |

## 2.4. Rotor design

The rotor has a set of 3 blades located at 120° to each other and with an angle of attack of 6°, joined by means of a 30 cm diameter girder that will be fastened to the blades with bolts. This set is of vital importance in the generator, so its dimensions are essential for the generation of electricity. The blades were designed by means of NACA 4412 profile which, highlighting the above, complied with the requirements of the design, this commercial profile being in the current market. Fig. 3 shows the design of the hydrokinetic turbine.

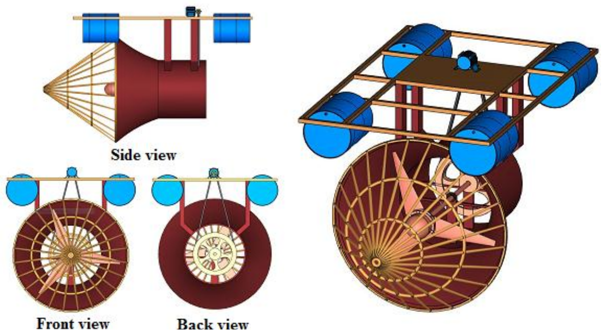


**Fig. 3:** Diagram of the Hydrokinetic Turbine.

## 2.5. Buoyancy

For the construction of the hydrokinetic turbine, it is necessary to calculate the buoyancy of the same, for the estimation of the sizes of the float tanks and thus obtain a stable flotation system. Fig. 4 shows the scheme for the calculation of buoyancy shown in equations 1 to 4.

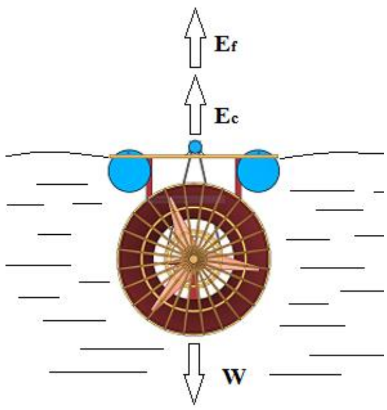


**Fig. 4:** Free-Body Diagram for Buoyancy.

$$\sum F_y = E_C + E_f - W = 0 \quad (1)$$

$$E_C + E_f = W \quad (2)$$

$$\rho_{H20} * V_c * g + \rho_{H20} * V_{tanque} * g = W \quad (3)$$

$$V_{tanque} = \frac{W - \rho_{H20} * V_c * g}{\rho_{H20} * g} \quad (4)$$

According to the dimensions used, an average mass of 98.6 kg is estimated for a volume $V_c$ of 0.00032 $m^3$. By data obtained in the field visits, we have a water density $\rho_{H2O}$ of 955.3 kg / $m^3$ and gravity being taken as 9.8 m / $s^2$. A volume of float tank $V_{tanque}$ of 0.10289 $m^3$ is obtained. In conclusion, on average 110 L tanks are needed to ensure that the structure floats.

## 3. Results and discussions

### 3.1. Analysis by finite elements

Using the design generated by CAD software (Computer Aided Design), it is prepared to perform the analysis by means of finite elements, which has two phases of the process as a whole, such as CFD (Computational Fluid Dynamics) coupled to an analysis Structural. The turbulence model k-epsilon (k-ε), an average velocity of 1 m / s, and the material properties mentioned in the design stage were used as working conditions. Obtaining, as a result, a maximum speed at the tip of the vanes of 2.7 m / s, which provides a rotation speed of 13.34 rad/s. The geometry of the blade in its middle part generates higher speeds than in the immediately adjacent sections, as a result of the section changes in the transversal areas of the profiles as shown in Fig. 5.

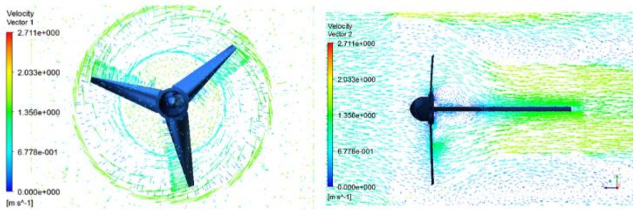


**Fig. 5:** Velocity Profile Through the Diffuser.

The Fig. 6 of Torque and angular velocity, indicates the energetic behavior of the hydrokinetic turbine in a transitory state. The torque increases in proportion to the angular velocity. The angular speed when reaching 4.55 rad / s reaches the required torque 84.77 Nm that is required to reach the power of 425 W which is estimated to satisfy the needs of the studied house.

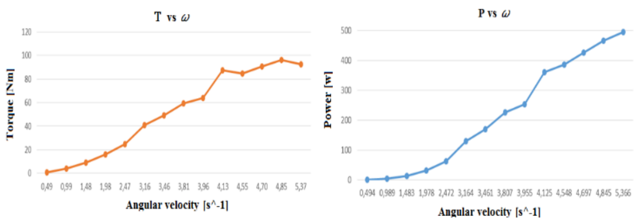


**Fig. 6:** Torque, Angular Velocity and Performance.

### 3.2. Structural analysis of the rotor

The pressure field on the blade shows that the maximum fluid pressures on the surface are reached at the leading edge. The pressures on the exit edge of the blade are significantly lower than the pressure on the leading edge, favoring the rotation of the rotor at low speeds. The rotor cover receives a high jet impact which produces fluid stagnation points on it and producing vortices after the passage of fluid through the rotor.

Fig. 7 shows the efforts of Von Mises for the design conditions of the hydrokinetic turbine. The distortion energy of the blades is concentrated in the central areas of each one, the combined effect of the rotation movement and the recoil of the surfaces thereof, and the relationship with the limit of the glass fiber. Which is 135 MPa. What meets the design conditions, ensuring that it will not fail elastically. The maximum value of the pressure in the middle areas of the blades is 17 MPa, which does not represent any danger to the physical and functional integrity of the turbine.

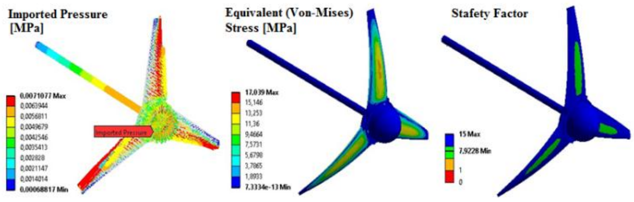


**Fig. 7:** Structural Analysis of the Rotor.

The maximum safety factor obtained in the design of the turbine is 15 in areas such as the edges of attack and exit and the tips of the blades. The central areas of the blades have lower safety factors due to the high strains that these areas are subjected [7]. Such a safety factor will favor better behavior of the turbine in front of different regimes and flow rates, to establish zones of safe operation of the equipment.

## 4. Conclusions

Base on field visits and data collection, it was found that on average a household located on the banks of the Magdalena river in the squid sector in the department of Bolívar needs around 2.78 kWh / day, it was observed that the appliances Electronic devices to be supplied in these homes can be generalized in bulbs, fans, radios, among others; therefore it does not exceed a monthly consumption of 83.55 kWh / month.

The cost of the manufacturing and the implementation of a hydrokinetic turbine to produce a power of 425 W, requires an investment of one thousand eight hundred twenty-eight thousand COP ($ 1,828,000).

A hydrokinetic turbine with a capacity of 425 W of power was designed, which within its design features consists of a diffuser that protects the life and the axis of elements which gives an answer to the body of the turbine, a protective cover that fulfills the same function without causing obstruction in the fluid, the whole system is anchored to a floating structure in order to facilitate maintenance and cleaning, the generator is located at the top of the whole structure, and in order to maintain an under cost the idea of a submerged generator was discarded.

The safety factor of the design stipulated by the CFD software after making the static structural analysis is 15, the maximum pressure that can be exerted on the frontal faces of the latter with the simulation conditions is 0.007 MPa, and the maximum rotor speed will be 2.7 m / s.

## References

[1] Kumar and R. Saini. (2017) Performance analysis of a savonius hydrokinetic turbine having twisted blades, Enewable energy 108, 502–522. https://doi.org/10.1016/j.renene.2017.03.006.

[2] G. Tampier, C. Troncoso and F. Zilic. (2017) Numerical analysis of a diffuser-augmented hydrokinetic turbine, Ocean engineering 145, 138–147. https://doi.org/10.1016/j.oceaneng.2017.09.004.

[3] T. Kinsey and G. Dumas. (2017) Impact of channel blockage on the performance of axial and cross- fl ow hydrokinetic turbines, Renewable energy 103, 239–254. https://doi.org/10.1016/j.renene.2016.11.021.

[4] A. José, P. Jerson, A. Alexandre and C. Claudio. (2015) An approach for the dynamic behavior of hydrokinetic turbines, Energy procedia 75, 271–276. https://doi.org/10.1016/j.egypro.2015.07.334.

[5] B. Daskiran, J. Riglin, W. Schleicher and A. Oztekin. (2016) Transient analysis of micro-hydrokinetic turbines for river applications, Ocean engineering 129, 291–300. https://doi.org/10.1016/j.oceaneng.2016.11.020.

[6] P. Fernández. (2002) IV.- Parámetros de diseño, Energía eólica 6, 65 – 91.

[7] E. battle, J. Romero, J. Fabregas, J. Villa, F. Quesada and J. Unfried. (2016) Strain analysis of an electromechanical device for force measurement in friction stir welding developed in a universal milling machine, Prospectiva 14, 36 – 44. https://doi.org/10.15665/rp.v14i2.749.