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PROJECT OF WATERWHEEL TO THE IGARAPÉ ARAPIRANGA-AÇU

Paulo Augusto Soares de Aquino
Instituto de Tecnologia-ITEC, Universidade Federal do Pará-UFPA
paulo_augusto_pa15@yahoo.com.br

Cássio Willian Corrêa Tavares
Instituto de Tecnologia-ITEC, Universidade Federal do Pará-UFPA
cassiowillian@yahoo.com.br

Ederson Santos de Freitas
Instituto de Tecnologia-ITEC, Universidade Federal do Pará-UFPA
ten_ederson22@yahoo.com.br

Jerson Pinheiro Vaz
Instituto de Tecnologia-ITEC, Universidade Federal do Pará-UFPA
jerson@ufpa.br

Arielly Assunção Pereira
Instituto de Tecnologia-ITEC, Universidade Federal do Pará-UFPA
arielly.@ufpa.br

Cláudio José Cavalcante Blanco
Instituto de Tecnologia-ITEC, Universidade Federal do Pará-UFPA
blanco@ufpa.br

Abstract. *The Amazon region has a great hydro potential with good water flow speeds, especially in small rivers, that is enough to implementation of hydro generator. Thus, in this work, develops the project for the implementation of a hydro type waterwheel for power generation that can be applied to the Igarapé Arapiranga-Açu, located in Tomé-Açu city, state of Pará, which aims reduce the costs and the rise of the vision of local society about the environmental development. This paper develops the applicability of the water wheel to the region, and thus, defines the characteristics that will provide a better relation cost benefit to the project. The project also aims to use accessible materials to construct of the system, and thus contribute to sustainable development and low environmental impact in the Amazon region.*

Keywords: *Waterwheel; Hydro generator; Power generation*

1. INTRODUCTION

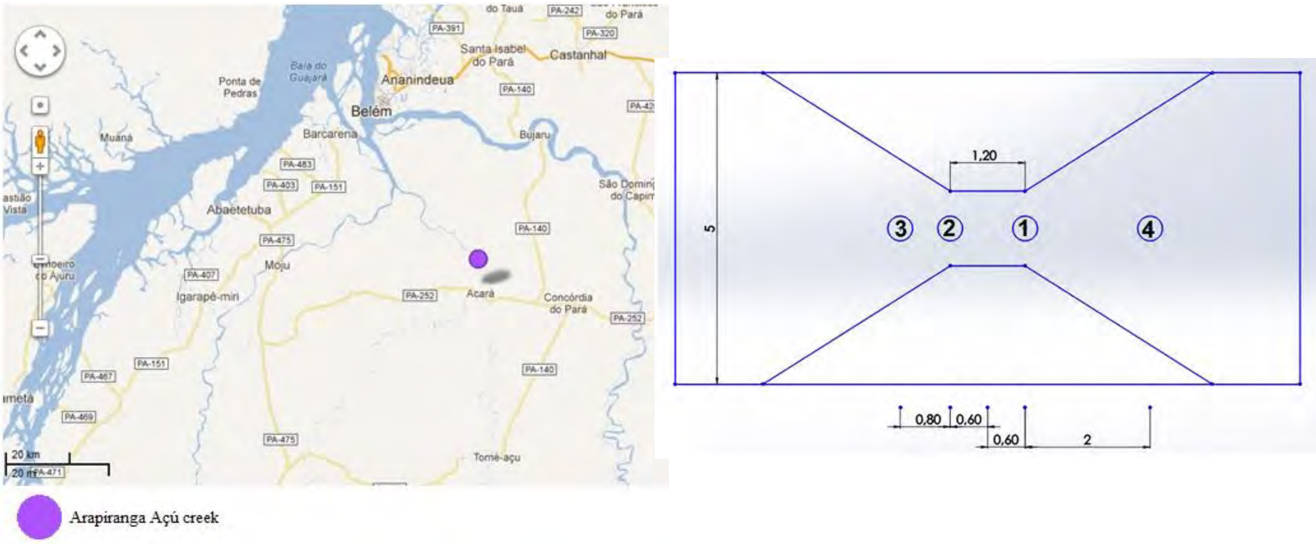
Rivers of Amazon region have substantial hydro potential and water flow rates sufficiently satisfactory to implementation of large and even small alternatives of power generation turbines. This study aims to adequate the experience of a developed work where a waterwheel was projected to receive the charge of a fixed water source Khan, T. and Zaman, A. (2012), to a classical method using mathematical and physical concepts of White, F. M. (1999), as comparative parameter, in order to propose a new mathematical formulation and modeling for output power generated.

A waterwheel is designed to convert the kinetic energy from rivers into energy axis, this kind of equipment has lower maintenance costs compared to other types of hydraulic turbines, the low influence over the natural course of the river, resistance to solid sediments in contact to the blades, great capacity for intermittent work and in this case, not requirement for waterfalls. This way, contrasting large and medium power-plant projects, such turbo-machine causes lower environmental impact and can provide social development for isolated communities in many parts of Brazil. This type of equipment is also normally used to irrigation of small plantations and riverside houses, and thus Arapiranga-Açú stream, located in Tome-Açú, state of Pará is a suitable place to the implementation of this project.

2. HYDRAULIC POTENTIAL OF THE IGARAPÉ ARAPIRANGA AÇÚ

The potential energy from the flowing river stands in northern Brazil. The Tucuruí Dam is a great example of the quantity of energy that can be generated in the region, providing energy for many cities. "Fig. 1 (a)" shows Arapiranga Açú creek and "Fig. 1 (b)" illustration of the creek's structure reduction, which has flow speeds ranging from 0 to 1.0

m/s. Such speed is not so significant for the generation of large energy demands. However, it's possible check the possibility of deploying small power generation systems, without changing the course of the river or interfere with aquatic life in the river arm Acará.



(a) (b)

Figure 1. (a) Location of the county Acará/PA (Image taken from google maps, on 30/04/2013). (b) Illustration of the structure on the Igarapé Arapiranga Açú.

Using the measuring equipment FlowTracker 3.7 serial No. P3646 it was measured the creek's velocities at a temperature of 26.8 ° C. Follows the table with data regarding the position of the meters and velocities in the X and Y axes.

Table 1. Velocities in *x* and *y* axes and position.

Position	V_x	V_y	V_r
1	0,477	0,156	0,501862
2	0,625	-0,053	0,627243
3	0,724	0,041	0,72516
4	0,209	-0,084	0,225249

According observed in "Table. 1", the speeds was determined at the points illustrated in "Fig 1. (b) ". Because of the structure applied in the river it's noted a significant increase of speed resulting from the creek, where at certain times of the year due to high tides, the resulting velocity reaches higher values.

3. DESIGN METHODOLOGY

3.1 Classical theory

This project was developed from studies done in the area of the hydropower, which through articles and books, a mathematical model was developed to obtain a theoretical power and finally compared to a method used by White F. M. (1999), for a floating waterwheel as shown in "Figure 2".

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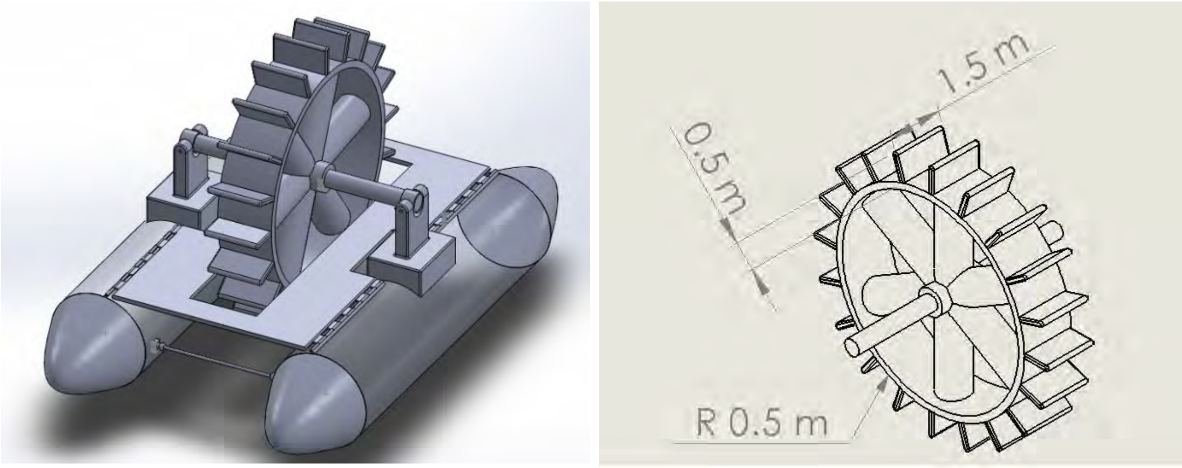

(a) (b)

Figure 2. (a) Schematic drawing of floating the water wheel. (b) Schematic drawing of the water wheel dimensions.

The concepts of this project were fundamentally based on the work of White F. M. (1999), referred in this work as classic model. From its theoretical principles of energy balance, mass and momentum were determined Force, Power output and Torque equations used as comparative model for Power output and Torque graphic results obtained by MATLAB® generated algorithms. These equations are:

$$F = \rho.Q.(V-u).(1-cos\beta) \tag{1}$$

$$P = F.u = \rho.Q.u.(V-u).(1-cos\beta) \tag{2}$$

Being F the normal force on the blade, ρ the density, Q the volumetric flow, V the jet speed, β output water angle, P generated power, and u the linear velocity, this last obtained by

$$u = 2.\pi.n.r \tag{3}$$

Being n the rotation, and r the distance between water wheel and blade centroids, as seen in “Figure 3”.

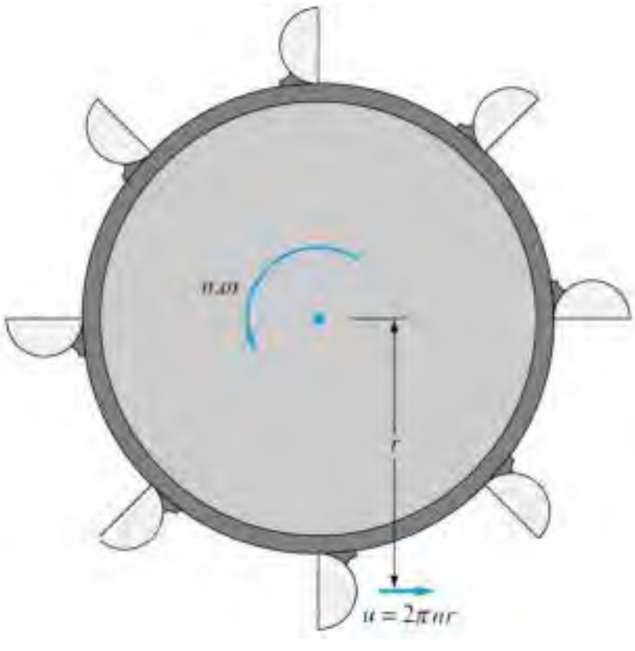

Figure 3. Schematic Design of the Water Wheel used for White F. M. (1999).

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For this project the classic model is u_{max}, was applied as:

$$u_{max} = \frac{V}{2} \tag{4}$$

Associating equations (3) and (4), rotation n is obtained like:

$$n = \frac{V}{4.\pi.r} \tag{5}$$

From these data, ϕ (Peripheral velocity factor) can be calculated Eq. (6), and though η (performance) Eq.(7), as follows,

$$\phi = \frac{u}{V} \tag{6}$$

$$\eta = 2.(1 - \cos\beta).\phi.(C_v - \phi) \tag{7}$$

Being C_v the linear velocity coefficient (in this work, C_v is a constant equals 1). Consequently, Torque can be calculated,

$$T = P.\omega^{-1} \tag{8}$$

ω is the angular velocity of the waterwheel, determined by:

$$\omega = 2.\pi.n \tag{9}$$

By the association of equations (8) and (9),

$$T = \rho.Q.u.(V - u).(1 - cos\beta).(2.\pi.n)^{-1} \tag{10}$$

3.2 Propused method

From the studies from Khan, T. and Zaman, A. (2012) been possible develop this project, using the formula:

$$P = \ .q.H.g \tag{11}$$

where H is the gross head, g is the gravity acceleration, P power output, power factor and q is the "usable flow rate". Considering the "formula (6)", it can be suggested the formula:

$$P = \ .\rho.Q.H.g \tag{12}$$

where ρ is density and Q is the flow rateConsidering the concepts observed in White F. M. (1999). Has changed the type of trigger of waterwheel, using the formula:

$$H = \frac{1}{2g}.V^2 \tag{13}$$

where V is the velocity. Associating the "formulas (6) and (7)" obtains a new proposal for calculating the power output generated theoretically, with:

$$P = \frac{1}{2}.\ .\rho.Q.V^2 \tag{14}$$

subsequently it was calculated the torque (T) by associating the equations (8) and (12), obtaining:

$$T = \ .\rho.Q.V^2.(4.\pi.n)^{-1} \tag{15}$$

4. RESULTS AND DISCUSSIONS

4.1 Results for the classical theory

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First of all, an algorithm was created in MATLAB® in order to find the best output water jet angle. As seen in the "Fig 4", the best angle β calculates was 180°, however, this angulation would not be physically possible, White F. M. (1999).

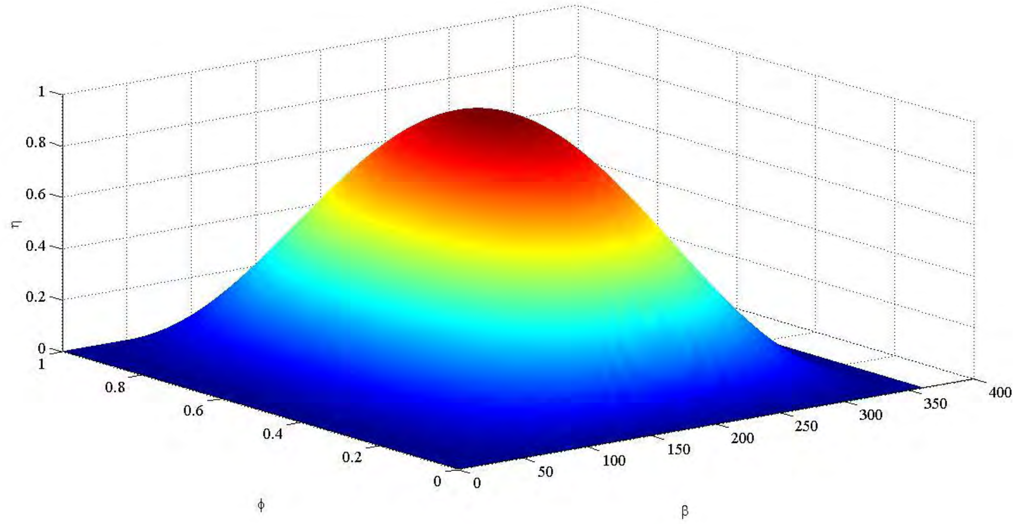
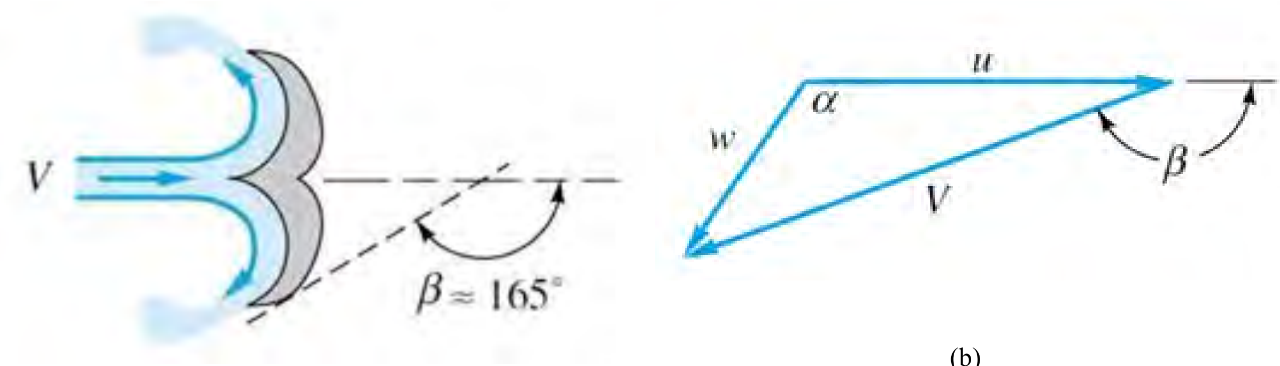


Figure 4. Efficiency as a function of β and ϕ.

By the observation of "Fig. 4", is possible to check that there is a performance decay associated to increase or decrease of β (ϕ is constant by association of equations 4 and 5). β= 165° was determined though as the best angle to apply because it presents only low rates of decay in performance, being possible the development of a real prototype.



(a)

(b)

Figure 5 (a). Schematic Design of β chosen. Schematic Design of β chosen. (b)

After analyzing equations number (4), (6) and (7), performance η assumes a constant value of 98,29%, since all other factors related to it are constant. Determining the angle β, Power and Torque can be obtained so.
The "Fig. 6" highlights association of equations (2) and (4), showing for White's classical model the exponential variation of Power output according to velocity's, and assuming a constant Performance of 98,29%.

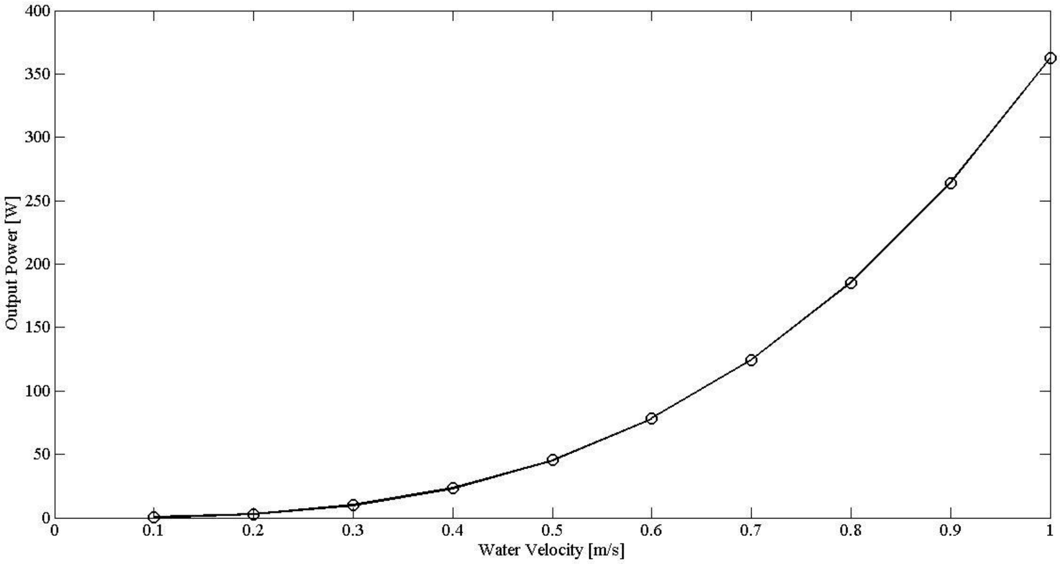


Figure 6. Output power as a function of velocity.

Since it uses identical parameters, Torque assumes the same graphical behavior of Power output in function of velocity as can be seen in "Fig. 7", this result can be observed through the analysis of equations (5) and (10)

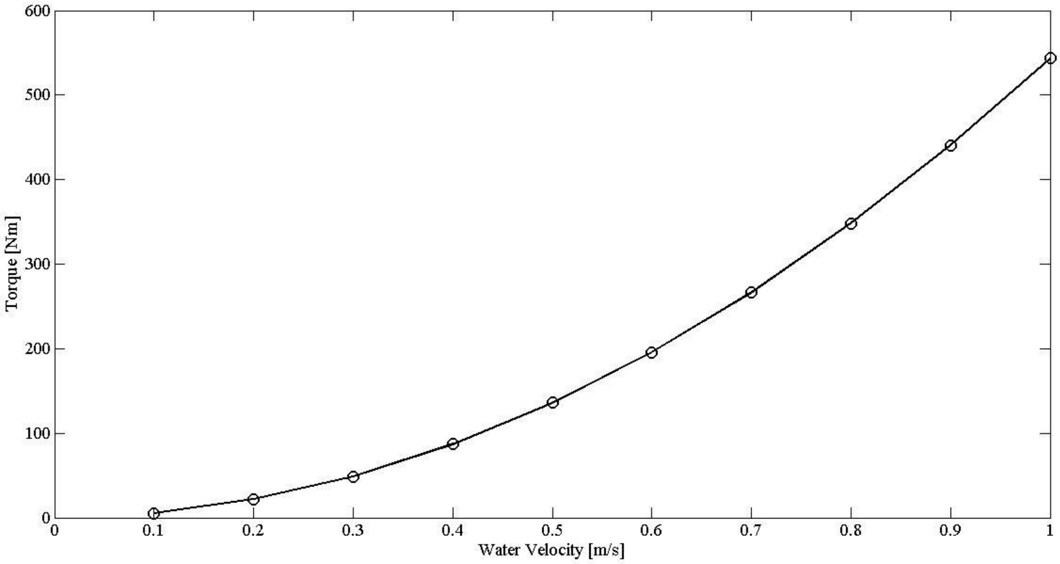


Figure 7. Torque as a function of water velocity

Rotation n analyzing considers only one variable factor, as seen in equation (5). This way, its graphical behavior is showed in the "Fig. 8" as a crescent line according to velocity increment.

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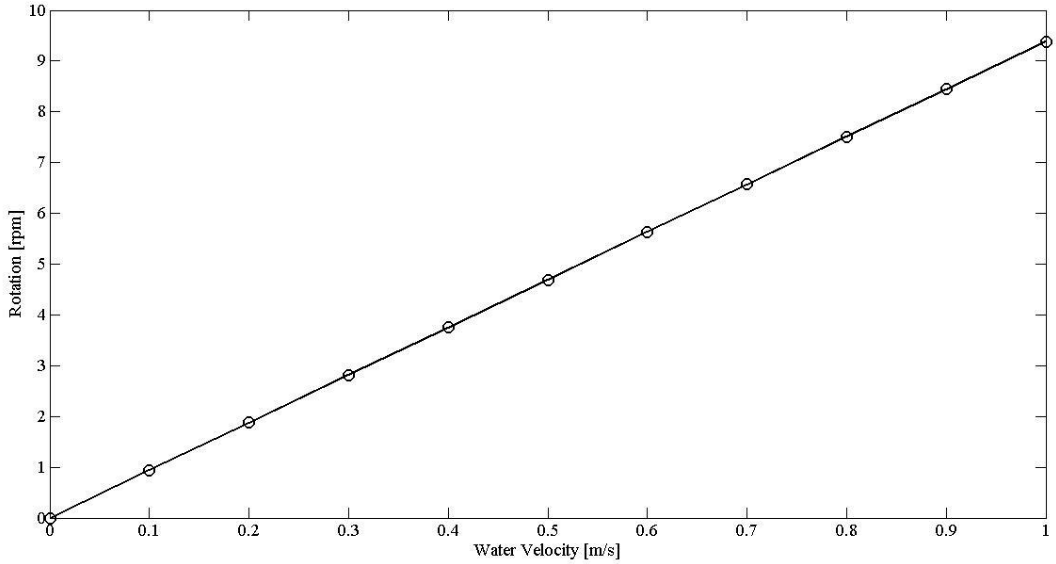

Figure 8. Rotation as a function of water velocity

4.2 Results for the proposed model

Applying equation 3.2, we can obtain the theoretical values related to power output, as can be seen under "Fig. 9", where the velocity interferes directly in the generated power, being possible to observe the low generated power, with a yield ranging from 0.5 to 0.7. However, such characteristic can still be increased when done studies of converting mechanical energy into electrical energy.

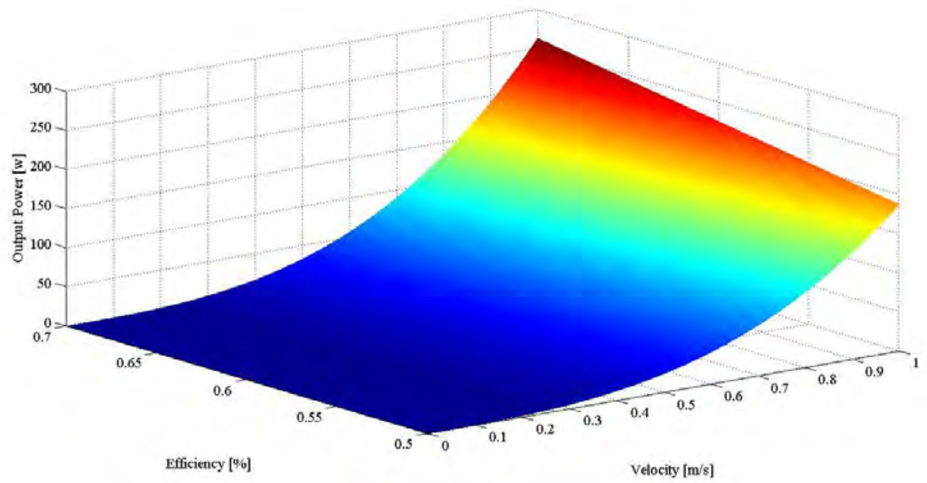

Figure 9. Power output as a function of Velocity and Efficiency, using the proposed model.

The speed factor directly influences the power generation because, as noted in "Fig. 9" with the increase of this factor notes' greater potency, as well as torque, discussed in "Fig. 10", one can observe that with increasing this same factor, there is a rise in the torque generated.

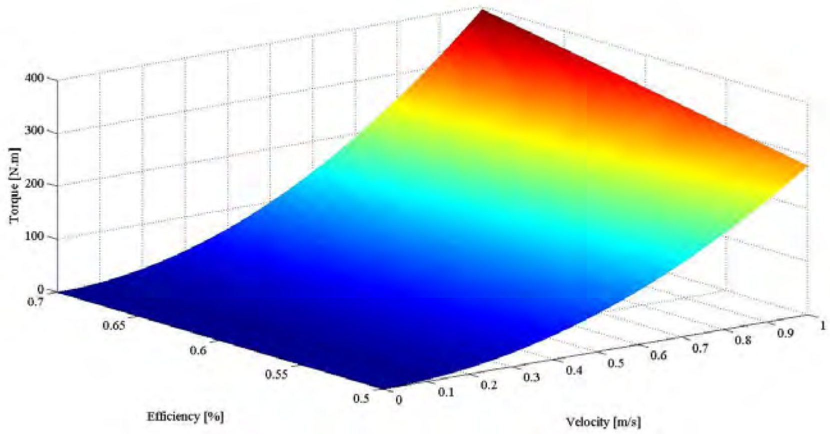

Figure 10. Torque as a function of Velocity and Efficiency, using the proposed model.

4.3 Comparative analysis of Results Generated.

The results of Power obtained by classic and proposed models are shown in "Fig. 11". The substantial differences between models are due to high performance applied in White's equations, which is very close to 100%, since the proposed model worked with performance ranging from 50% to 70%.

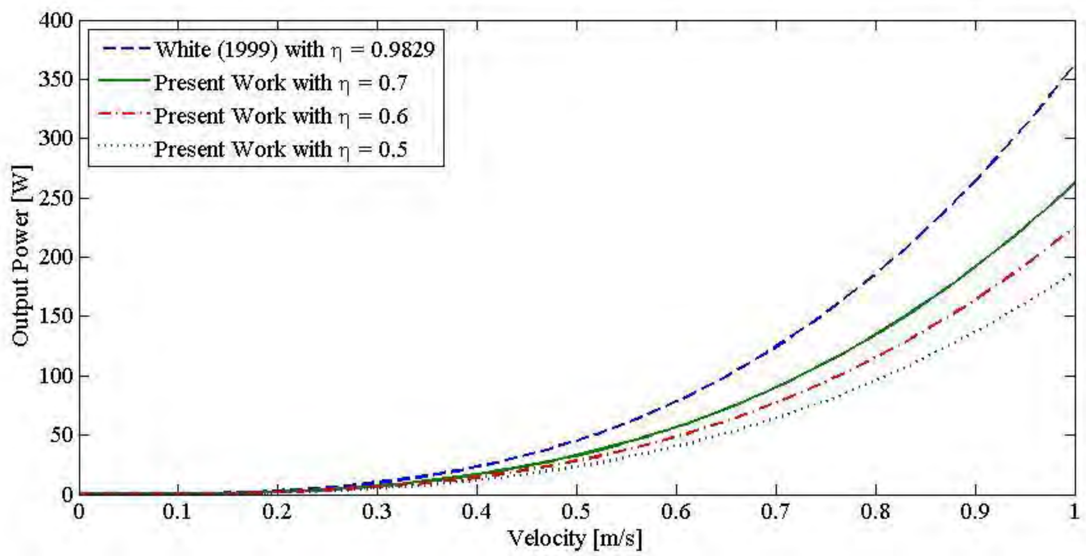

Figure 11. Power output as a function of Velocity, using the various values of performances.

The same remarks can be made when Torque results are plotted in function of velocity, as seen in "Fig. 12".

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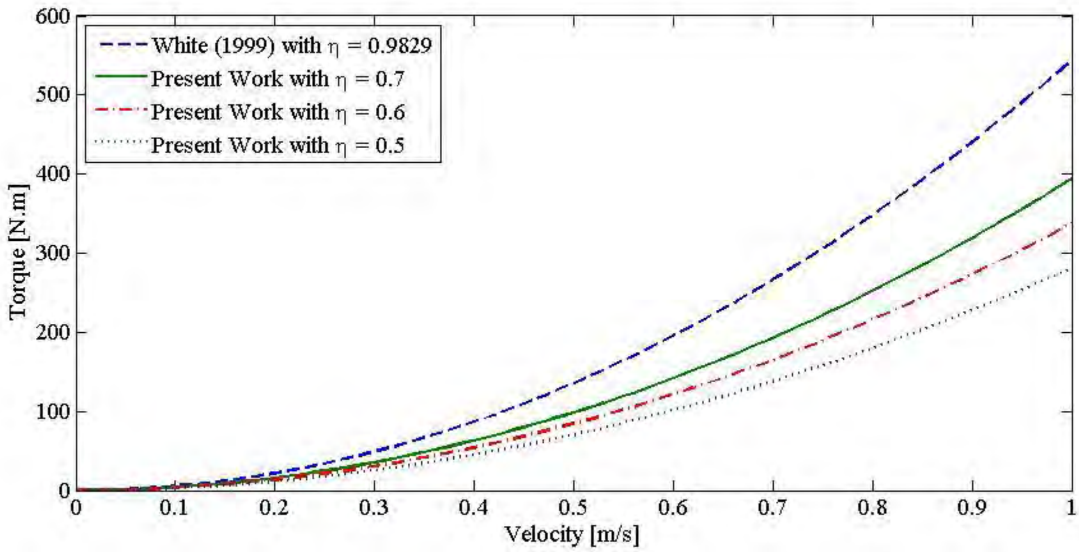

Figure 12. Torque as a function of Velocity, using the various values of performances.

5. CONCLUSIONS

The development and improvement of technologies that appear as viable alternatives for the generation of electricity with minimum environmental impact has represented a major challenge for the modern world. In this context, the potential energy of water resources in the Amazon region can mean a great alternative to the implementation of waterwheels as the proposition of this work. The results were obtained from the adoption of a classical model of White (1999) as a parameter of comparison and combination with the physical and mathematical concepts of Zaman and Khan (2012), from which the generation of power and torque achieved good levels considering the dimensioning of the waterwheel and given the conditions of flow velocity in Arapiranga Açú creek. This study still needs experimental application of the proposed equipment, which should provide new data and the possibility of substantial improvement in the project as a result of deepening the theme.

6. REFERENCES

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7. RESPONSIBILITY NOTICE

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