Hydrokinetic turbines for electricity generation in isolated areas in the Brazilian Amazon

Kamal A.R. Ismail, Tiago P. Batalha, Fatima A. M. Lino

Abstract— **Isolated areas in Brazil are usually served by diesel based electricity supply. The diesel fuel is usually transported by river to these isolated communities. During dry, wet seasons and inundations the transport is very risky and not usually safe. As a result the communities have to manage without electricity. To guarantee access of these communities to reliable electricity supply, better strategies have to be implemented based on renewable energy sources available in the area. The hydrokinetic technology is among the promising technologies since it is relatively cheap, easy to manufacture, reliable and suitable for most of the Amazon areas. In this paper the authors propose a cheap hydrokinetic turbine system whose blades are easy to design, manufacture, and needs simple transmission systems. In this work CFD and RANS (Reynolds Average Navier Stokes) equations were used to characterize and develop a methodology for numerical simulation of a vertical axis hydrokinetic turbine. In the simulations, different blade profiles were useds such as flat plate and circular arc. The effects of the number of blades, blade profile and water flow velocity on the turbine torque and power coefficients were presented and discussed.**

Index Terms—**Renewable energy, hydrokinetic turbine, vertical axis turbine, circular arc profile, flat plate profile.**

I. Introduction

According to United Nations about 1.4 billion people or 20% of the global population do not have access to electricity and a further 1 billion lack reliable access to it. Almost 40% of the global population relies on use of biomass for cooking. Specifically Brazil, the fifth most populated country in the world, like other developing countries faces problems of the continuous increase of the population and of the demand for additional energy supply to cope with the industrial and economic growth.

The continuous increasing demand for electric energy, the necessity of avoiding aggressions to the environment, ambient and geographic difficulties of extending electricity transmission lines across the dense Amazon forests and extensive rivers, are some of the reasons for enhancing the use of small capacity renewable technologies for remote and isolated areas.

Among different renewable energy technologies, hydro-power generation seems to be the most adequate solution for providing energy on large and small scales. However, large-scale hydropower plants need large dams, huge water storage reservoirs and in most cases inundate a large forest area creating local dislodgements of the natives, animals and exterminating natural life in the region. Alternatively, small scale hydropower plants of different concepts have been developed and tried out with reduced impact on the environment. Hydro kinetic or in-stream turbines have received a growing interest in many parts of the world especially in relation to river applications. They can convert the kinetic energy of a flowing stream into electricity by adequate generators without the need for dams or barrages and can be installed in any flowing stream with velocity above 0.5 m/s. Small initial and maintenance costs makes this technology cost effective in comparison with other technologies.

In Brazil, many remote communities and small farms are scattered over the Amazon area and are surrounded by rivers and lakes adequate for this application. Hydro-kinetic turbine for electricity generation is a useful tool for improving the quality of life in isolated areas and a drive for stimulating local economy.

Water current turbines generate electricity using the kinetic energy of natural water streams. These turbines can be broadly divided into two groups: horizontal axis turbines (axial turbines) and vertical axis turbines (cross flow turbines). Horizontal axis turbines are mainly used for extraction of the ocean energy and are expensive for small power applications. Vertical turbines are generally used for small scale power generation, cheaper and require less maintenance compared to horizontal axis water turbines.

Khan *et al*. [1] reviewed the technology status of hydrokinetic energy conversion systems and presented assessment of horizontal and vertical axis turbines for river and tidal applications and a comprehensive review of the existing and upcoming conversion schemes.

The river current turbine is one of the preeminent clean decentralized renewable energy technologies in delivering locally the energy for communities inaccessible by the electricity distribution systems. Rachman *et al*. [2] presented a mathematical model based on blade element theory for a river current turbine with a horizontal axis rotor arrangement.

The Savonius rotor is simple in design and easy to manufacture at low cost. The basic driving force of Savonius rotor is the difference in the drag force between the advancing blade and the returning blade which produces torque and rotation of the rotor. Net driving force can be increased by reducing the reverse force on the returning blade by providing a

Kamal A. R. Ismail, Full Professor, State University of Campinas, Faculty of Mechanical Engineering, Energy Department, Mendeleiev street, 200, Cidade Universitária "Zeferino Vaz", Barão Geraldo, Campinas, SP, Brazil, Postal Code 13083-860, Phone: +55 19 35213376, Fax +55 19 32893722

Tiago P. Batalha, M.Sc., State University of Campinas, Faculty of Mechanical Engineering, Energy Department, Mendeleiev street, 200, Cidade Universitária "Zeferino Vaz", Barão Geraldo, Campinas, SP, Brazil, Postal Code 13083-860.

Fátima A. M. Lino, PhD, State University of Campinas, Faculty of Mechanical Engineering, Energy Department, Mendeleiev street, 200, Cidade Universitária "Zeferino Vaz", Barão Geraldo, Campinas, SP, Brazil, Postal Code 13083-860, Phone: +55 19 35213376,

flow obstacle in front of the returning blade. Golecha *et al*. [3] presented a study to find out the optimal position of the deflector plate which would result in maximum power generated by the rotor.

Malipeddi and Chatterjee [4] performed a computational study to develop a new duct to improve the performance of a straight-bladed Darrieus hydro turbine. In their study, a new duct is developed, which reduces the variation in torque over a cycle by appropriately directing the flow upstream and downstream the turbine while increasing power conversion.

Hu and Du [5] realized a reliability analysis for hydrokinetic turbine blades. They performed time-dependent reliability analysis for the blades of a river-based horizontal-axis hydrokinetic turbine. The results indicate that setting a proper cut-out river velocity is important for the reliability of the hydrokinetic turbine blade.

Kusakana and Vermaak [6] investigated the possibility of using and developing hydrokinetic power to supply reliable and sustainable electricity to rural areas in South Africa where reasonable water resource is available. They pointed out some major challenges for the development of this technology in South Africa.

Schleicher *et al*. [7] presented a preliminary micro hydrokinetic axial turbine with a 0.5334 m diameter rotor designed to generate 500 W of continuous power over the widest range of operating conditions possible, while maintaining portability and fast-deploy characteristics.

Sarma *et al*. [8] reported the results of an experimental and computational evaluation of Savonius hydrokinetic turbine for low velocity condition in comparison to Savonius wind turbine at the same input power. The hydrokinetic turbine showed enhanced performance compared to the Savonius wind turbine.

Vermaak *et al*. [9] presented a critical review on the current status of micro-hydrokinetic river technology for rural applications. Their findings can help researchers to identify areas that need improvements as well as encourage public bodies to implement proper energy policies in rural areas.

Fernandes and Rostami [10] studied an innovative turbine that consists of a vertical flat plate, which is allowed to rotate freely about a vertical axis of symmetry and exploited the autorotation phenomenon to harvest the energy from the current.

Acharya *et al.* [11] reported the results of a study on performance enhancement of a cross-flow hydro turbine. They analyzed numerically the characteristics and fluid flow in a cross-flow hydro turbine and optimized its performance by modifying some geometric parameters.

Small scale hydropower plants are an attractive alternative to highly polluting and costly diesel generators, especially to those communities difficult to reach during the rainy seasons in the Amazon areas. Since many isolated communities are settled near moving water streams, as in the Amazon, this technology is a promising source of clean energy. The vast territorial extension associated with the small population density of some areas, especially in the Amazon tropical rainforest. This creates good opportunities to implement small systems to generate energy to attend the needs of the community.

II. BRAZILIAN ENERGY PANORAMA

According to the EIA (Energy Information Administration), renewable energy incorporate only 0.6% of the Brazilian energy matrix, which is dominated by large hydroelectric power plants (75%) and thermoelectric power plants (22%).

Within this panorama, a river current turbine is one of the potential clean decentralized renewable energy technologies adequate for local energy delivery to isolated and remote communities in Brazil, such as many communities in the Amazon rainforest. According to Khan *et al*. [1], one of the preeminent advantages of this technology refers to the operation at almost zero potential head and consequently little or no civil work and less environmental impacts compared to the conventional water power technologies. Although it is not known whether these technologies will harm aquatic organisms, a number of possible negative effects have been identified, some as a consequence of the new structures that would be placed in the aquatic environment [12].

Investigations indicate hydrokinetic energy potential of approximately 1 TW in accessible sites around the world. According to the EPRI (Electrical Power Research Institute), viable sites for commercial production of energy require pluvial currents of at least 1.5 m/s or greater [13]. Other studies indicate water currents of 1.0 m/s or at least 0.5 m/s for reduced scale applications such as those intended to small isolated communities.

The natural hydrokinetic potential of the Brazilian rivers, estuaries and oceanic tides is practically unexplored. The tropical weather of Brazil originates several rivers of high water volume, which have usually pluvial origins, with the exception of the Amazon shelf which has its origin related to the ice melting on the Andes. Besides the large amount of water, several rivers flow on plateaus and depressions, originating several waterfalls and bottlenecks of high natural energetic potential. Only the Amazon river is responsible for one fifth of the total pluvial flow in the world and has a mean annual water discharge into the Atlantic Ocean of approximately 1.8×10^5 $m^3 s^{-1}$,[14].

The population density in the amazon region is very low, and is sparsely distributed along the rivers courses. Most of these communities still have serious infrastructure problems such as access to electric energy. The implementation of decentralized systems to generate energy by means of hydrokinetic turbines is an excellent economic and ambient alternative to replace diesel based generators for supplying energy to these communities.

Another region of good hydrokinetic potential is the Rio de Janeiro Shelf, which runs from the south of Brazil near the Paranagua Seaport till the Espirito Santo State. Annual average waterflow velocity near 2.24 m/s was measured near the Paranagua River estuare [14]. Detailed studies have been carried on some of the most important rivers and potential regions south and southest of Brazil to establish the best sites to install hydrokinetic turbines. One example is the Ivai River, of the Parana River Shelf. Measurements in this river revealed a maximum water velocity of 1.20 m/s at a depth between 2 and 4 meter below to water surface [15].

Perhaps the biggest problem and a possible limiting factor to the progress of turbine application in rivers is debris. Therefore installations implemented in tropical countries may experience serious debris problems since tropical rivers normally flow through thick forests collecting lots of leaves, grass, vines and other jungle trash. Sometimes huge amounts of such debris including uprooted trees may move down the river at high speed during flash floods and damage turbines installed in the river. To ensure efficient and safe operation, well designed turbines with smart debris management strategies must be planned [16].

The main objective of this paper is to investigate a hydrokinetic turbine of simple blade configuration and evaluate its performance in the Amazon rivers. The paper uses Computational Fluid Dynamics and RANS (Reynolds Average Navier Stokes) equations to characterize and develop a methodology of numerical simulation of a vertical axis hydrokinetic turbine of different blade profiles that are easy manufacture. These blades are the flat and circular arc profiles. The effects of the number of blades, blade profile and incoming water velocity on the turbine torque and power coefficients were presented and discussed.

III. MATH VERTICAL AXIS HYDROKINETIC TURBINE (VAHT)

The hydrokinetic turbine transforms kinematic energy of water streams acting on a moving rotor coupled to an electric generator, into electric energy. The coefficient of torque and the coefficient of power, two important parameters in the analysis of hydrokinetic turbines performance are determined by:

$$C_T = \frac{T}{\frac{1}{2}\rho V_o^2 S_{ref} R} \qquad (1)$$

$$C_P = \frac{P}{\frac{1}{2}\rho V_o^2 S_{ref} R} = \lambda C_T \qquad (2)$$

where T is the torque developed by the device, ρ is the specific mass of water, V_o is the upstream velocity of incoming water, S_{ref} is the cross section area of the rotor disc, R is the radius of the rotor. P is power developed by the device, while λ is the tip speed ratio.

According to the Betz Limit, which is independent of the turbine design, the maximum power coefficient developed by an ideal actuator disk, in an open flow condition is 59.3%, for a speed ratio (Rotor exit velocity/Rotor inlet velocity) of 1/3. Irrespective of the simplifying assumptions of axial flow and constant density, this power coeficient limit and its behavior with the speed ratio are usually taken as a baseline for the design of wind and hydrokinetic turbines.

Some modifications were investigated to try to achieve power coefficients higher than the limits determined by Betz. The use of ducted turbine increases the power density while the use of deflector plates can avoid undesired water flow effects.

Although the efficiency of vertical axis turbines is usually lower in comparison with horizontal axis turbines. The vertical axis rotor arrangement offers some advantages for hydrokinetic applications. These advantages include less susceptibility to cavitation problems due to its low tip speed, less impact on the aquatic life due to its reduced rotational speed, positioning the electric generator above the water surface with simple transmission mechanisms and floating platform and ease of stacking on a centralized structure. In general, river currents offer considerably less energy than ocean currents. Therefore, river energy conversion systems should have simple solutions for generators and speed control. Power transmission and generator of vertical axis hydrokinetic turbine can be assembled above water level and this facilitates the design, operation and maintenance of the system [17].

Although VAHT is relatively simple device as in Fig.1, the surrounding flow is complex. As the turbine rotates, the blade elements encounter their own wakes and those generated by other blades. The aerofoil section experiences a variation of incidence and strong unsteady effects in the flow field [18]. Due to these difficulties the use of computational methods based on finite differences, finite element and control volumes techniques are time consuming and of relatively low precision. To analyze the details the flow field near the blades of a VAHT. Computational Fluid Dynamics (CFD) is a viable tool to ensure accuracy and detailed characterization of VAHT flow field.

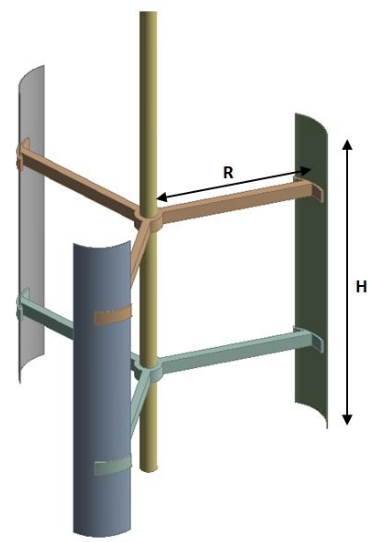


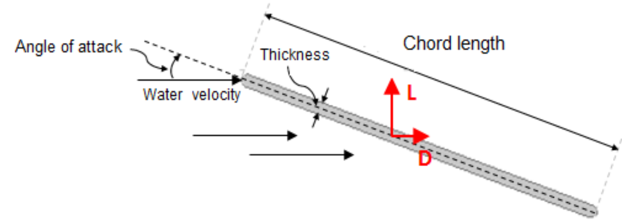
Fig. 1 Vertical axis hydrokinetic rotor with three blades.

The drag and lift forces on the blade will generate the torque around the turbine shaft:

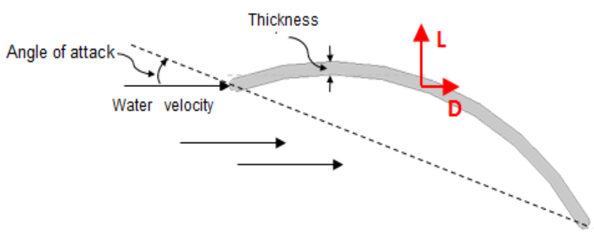
$$T = R(L\cos\alpha - D\sin\alpha) \qquad (3)$$

where L is the lift force, D is the drag force and α is the angle of attack.

The lift (L) and drag (D) arise from the pressure and shear stress differences on the surface of the blade. The profile of the blades and the angle of attack determine the lift and drag coefficients, fig. 2. For VAHTs the large variation of the angle of attack also leads to variations on the turbine torque and shaft loads.



(a) Flat plate profile



(b) Circular arc profile

Fig.2 Investigated profiles, a) Flat plate profile, b) Circular arc profile.

IV. Computational Treatment

This section contains the selection of computational grid, validation of the numerical simulations, results of single blade rotor, approximate superposition of the single blade element to form a turbine rotor with multi blades, and finally results of the dynamic simulation of multi blade rotor. Effects of blade shape, number of blades and rotor tip velocity are presented and discussed.

Computational Fluid Dynamic Analysis was carried out to simulate the VAHTs. Fig. 3 depicts the computational mesh used to discretize the fluid domain. The refinement of the mesh is compatible to the turbulence model (k - ε) employed in the simulation. Numerical tests were realized to determine the number of computational elements which makes the simulation results independent of the grid elements. A million computational elements were considered adequate as a compromise between precision and computational time. Of the million computational elements, 600 thousand elements were used for refinement near the blade but not on its surface, while the other 400 thousand elements were used in the general domain and in the layers near the blade surface. The curves are omitted for brevity.

VALIDATION OF CFD SIMULATIONS

Simulations were realized for the NACA 0018 profile and the results were compared with numerical results realized by Sheldahl and Klimas [19] of Sandia National Laboratories (1981) for Reynolds number of 10000. The total average error was found to be 6.8% in case of the drag coefficient and 1.1% in case of the lift coefficient for range of variation of angle of attack de 0^o to 180^o as shown in fig.4. The agreement between the numerical predictions and the experimental results are good and hence validating the CFD results [20].

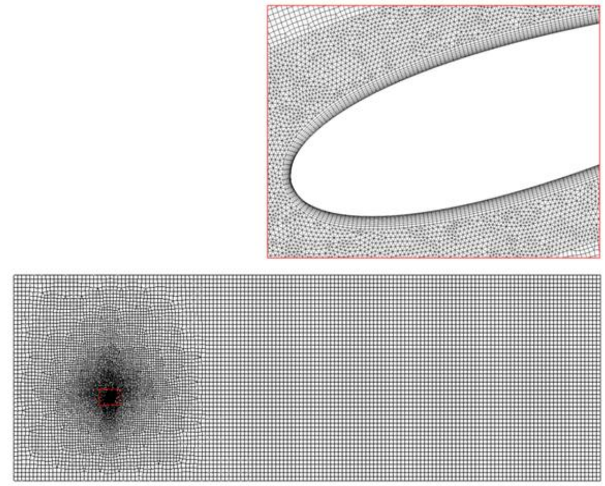


Fig.3 The computational mesh used to discretize the fluid domain.

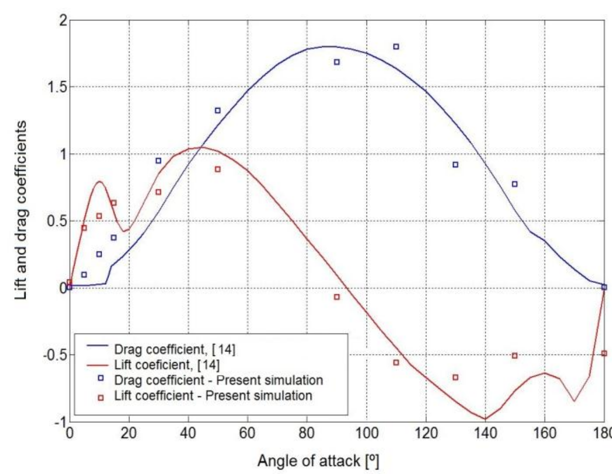
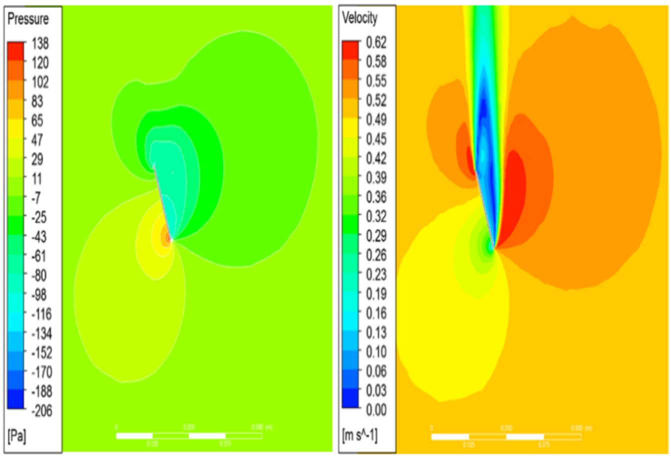


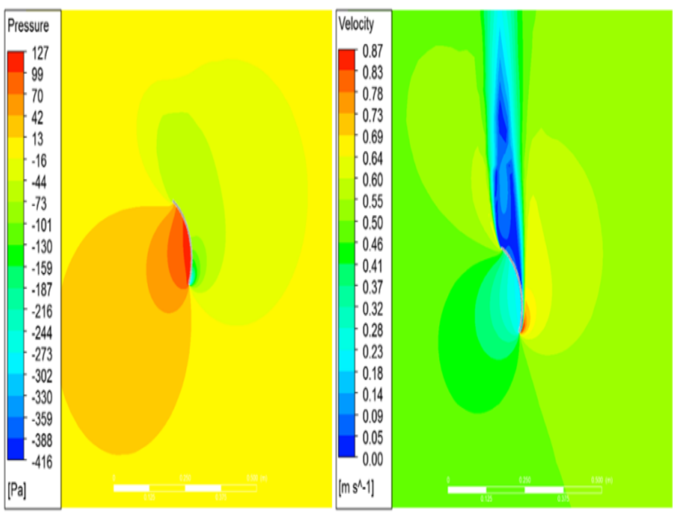
Fig.4 Simulations of NACA 0018 profile and the results were comparison with the results of Sheldahl and Klimas [19].

V. RESULTS AND DISCUSSION

Since the main objective is to search for a cheap turbine rotor for application in isolated regions, two geometrically simple profiles easy to design and manufacture and has analytical solutions were selected. In order to determine the influence of the blade geometry on the torque coefficient, the two profiles were analyzed in a steady-state CFD simulation. Fig.5 shows the results of pressure and velocity distribution around a flat plate profile and a circular arc profile for an azimuth angle of 0º and angle of attack of 20º.



(a)



(b)

Fig.5 Pressure and velocity distributions around flat plate and circular arc profiles for an azimuth angle of 0º and angle of attack of 20º.

Fig.6 displays the torque coefficient obtained from a single blade simulation in different azimuth angles. The flat plate profile presented an expected symmetric response, and consequently a small value of average torque coefficient, 0.003, against a value of 0.036 for the circular arc profile. The amplitude of variation of the torque coefficient is approximately 0.178 for the flat plate profile, against 0.183 for the circular arc profile.

The results from the single blade simulation may be superposed to determine a preliminary estimate of the torque coefficient for multi bladed turbines. This approach is simple but not accurate since it assumes that there is no interference among the blades. It was included here to have a quick idea of the variation of torque coefficient and the corresponding ripples.

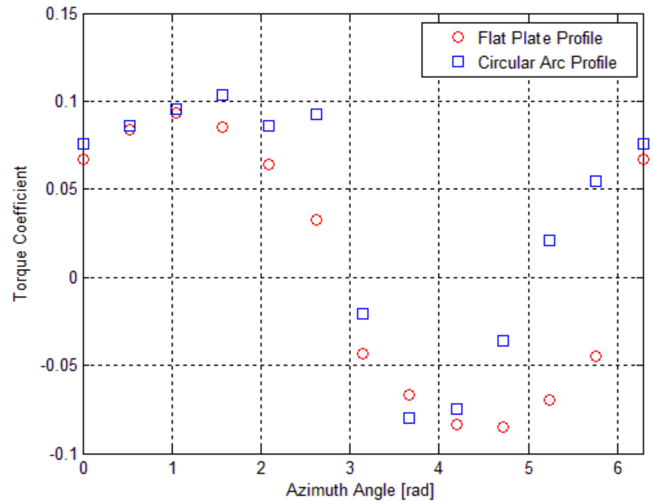


Fig.6 Torque coefficient obtained from a single blade simulation in different azimuth angles for the flat plate and circular arc profiles.

It is expected that the increase of the number of blades, and consequently of the solidity, will increase the average torque as well and decrease the amplitude of the ripples in the torque coefficient, fig. 7. The solidity is determined from

$$\sigma = \frac{Nc}{2\pi R} \tag{4}$$

where N is the number of blades and c is the chord length.

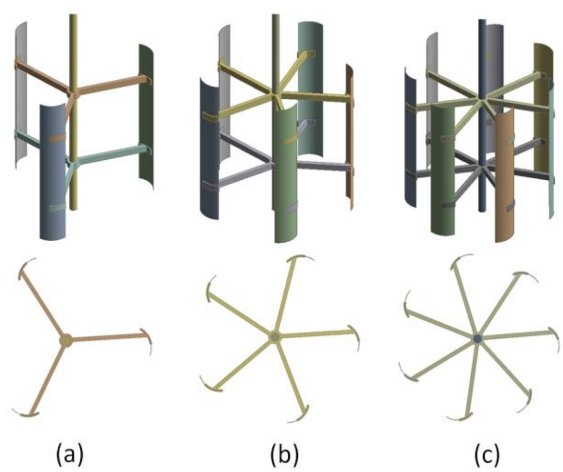


Fig.7 Rotors with different number of circular arc blades.

A turbine of 500 mm radius in the seven blades configuration presents high solidity (σ), near 0.40 against 0.17 and 0.29 for the three and five blades configurations, respectively. In the case of the turbine with three blades, the flat plate profile achieves mean torque coefficient near 0.005 and amplitude of variation of the torque coefficient near 0.076. The circular arc profile presents an average torque coefficient near 0.100 and amplitude of variation of the torque coefficient near 0.041, as in fig. 8.

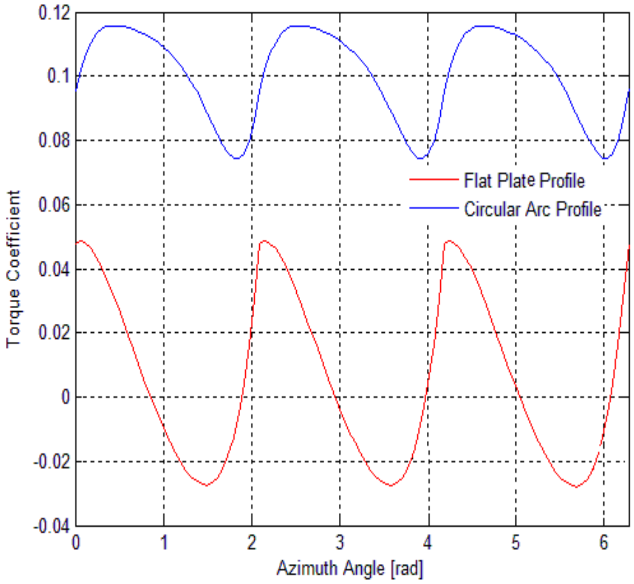


Fig.8Variation of the torque coefficient with the variation of the azimuth angle for the cases of flat plate and circular arc rotors with three blades.

The same tendency is found for the turbine with five blades. The flat plate profile achieved low average torque coefficient, while the circular arc profile achieved higher average torque coefficient, as in fig. 9. The turbine with seven blades and circular arc profile, Fig.10, achieved average torque coefficient near 0.234 and amplitude of only 0.020.

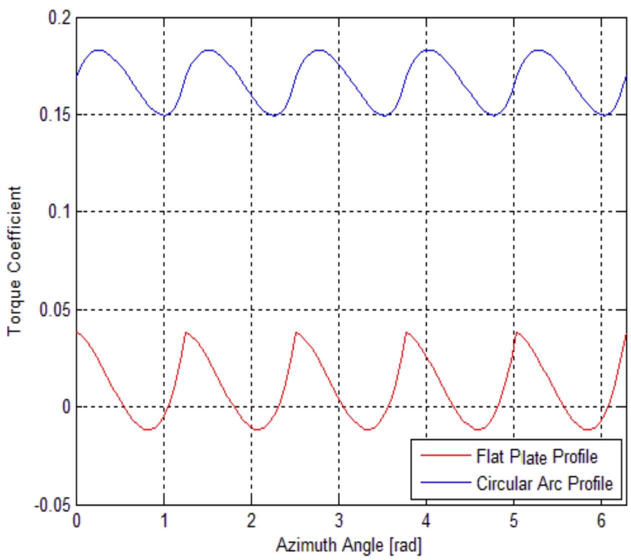


Fig.9 Variation of the torque coefficient with the azimuth angle for the cases of flat plate and circular arc rotors with five blades.

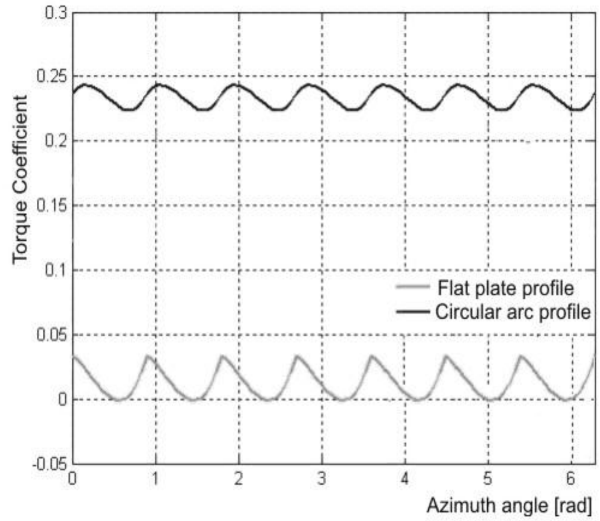


Fig. 10 Variation of the torque coefficient with the azimuth angle for the cases of flat plate and circular arc rotors with seven blades.

Fig. 11 shows a summary of the results of the flat plate and circular arc profiles. As can be seen the average torque coefficient of the circular arc profile is much more than that of the flat plate profile and increases with the increase of the number of blades. The reduced values from the flat plate profile are basically due to the nearly equal asymmetric pressure distribution on its two surfaces.

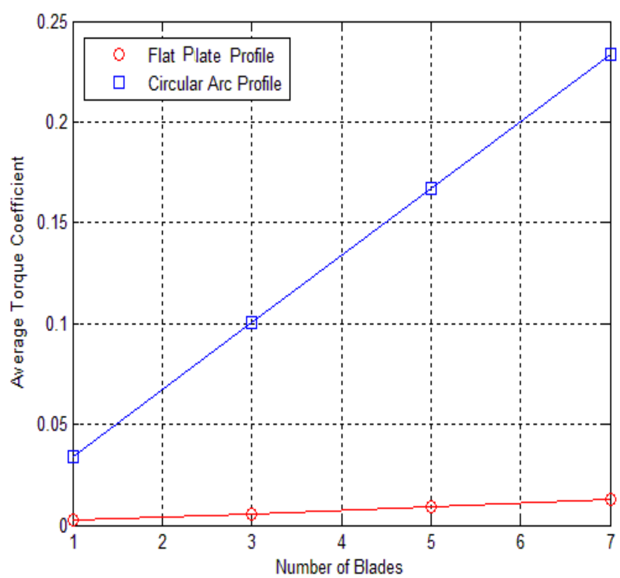


Fig.11 Comparison of the average torque coefficient produced by the flat plate and circular arc profiles rotors.

Information obtained by superposition of the single blade results to obtain the average torque for multi bladed rotors is instructive and consumes less computational time but unfortunately overestimates the mean torque coefficient since it does not consider the interaction between the turbine blades. It was used here to have a quick idea of the effects of the number of blades on the performance of the rotor, but can not be considered as a suitable tool for turbine analysis.

With the increase of the number of blades, the wake and turbulence generated by one blade affect intensely the flow on the neighboring blades decreasing their produced torque and consequently the turbine torque.

The static simulation is a better way of investigating the flow field effects and the number of blades at relatively low computational cost. This time of simulation is still not adequate for the precise analysis and assessment of the rotor. In the case of the whole rotor with five blades shown in fig 12, one finds that blade number 2 is affecting the flow around blade number 5, while blade number 3 is affecting the flow around blade number 4. At this azimuth position the flow near blade number 1 is less affected by the other blades of the rotor. These interactions change in intensity and location with the continuous change of the azimuth angle impairing the quality and uniformity of the flow field. The interaction among the blades is responsible for the low torque coefficient found in the simulation with the complete set of blades, since one blade may hide other blades behind it, and consequently the resultant torque coefficient is usually lower when this interaction is considered.

A better way of analyzing the flow field around the rotating multi blades of rotor is to consider the dynamic situation when the turbine is in rotation. This type of simulation, although consumes lots of computational time, enables the analysis and assessment of dynamic phenomena occurring during the movement of the multi blade rotor. The strong interference effects, vortex shed in the blades wakes, turbulence and shear stresses in the turbulent wake behind the rotating blades tend to impair the flow field around the rotating blades and reduce the torque coefficient of the rotor. The flow field for this case is shown in fig. 13.

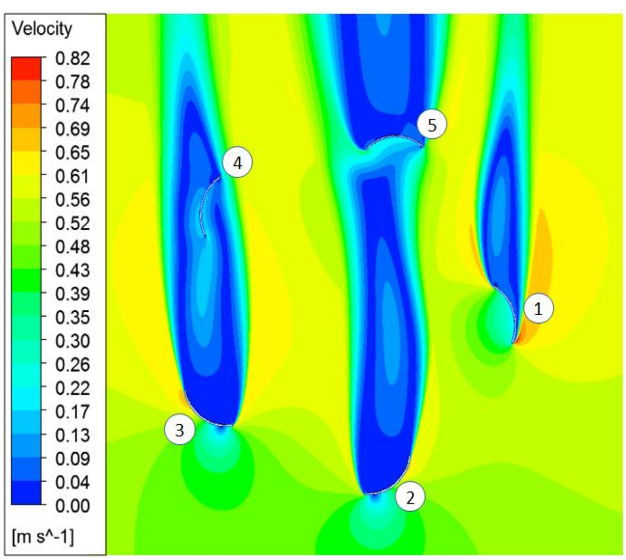


Fig.12 Static simulation flow field of a rotor with five blades.

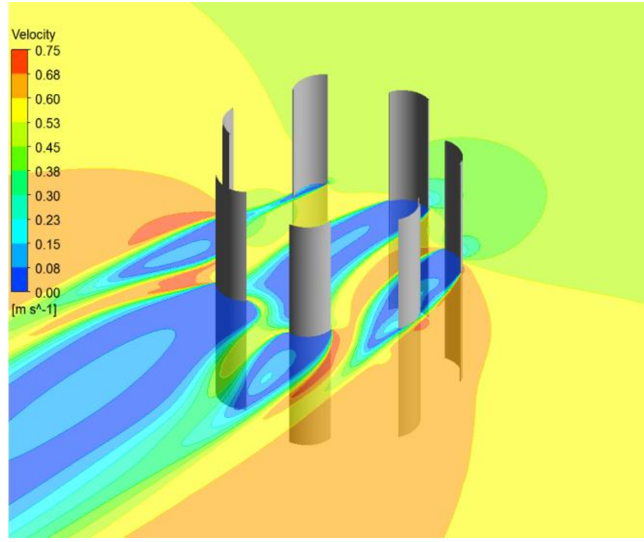


Fig.13 Dynamic simulation of the flow field around a rotating rotor with seven circular arc blades.

Because of the extensive computational time consumed in these dynamic simulations, we had to restrict the simulations to the case of circular arc profile at a tip speed ratio (λ) of 1.25. The torque coefficient for this case is shown in fig. 14. The influence of the increase of the number of blades on the average torque coefficient and on its amplitude is evident. The turbine with three blades presents average torque coefficient of 0.050 while the turbine with seven blades reaches 0.117. In addition, the amplitude of variation of the torque coefficient is approximately 0.057 for the turbine with three blades and goes down to 0.039 for the turbine with seven blades. Furthermore, the average power coefficient achieves 0.063 for the turbine with three blades and 0.147 for the turbine with seven blades.

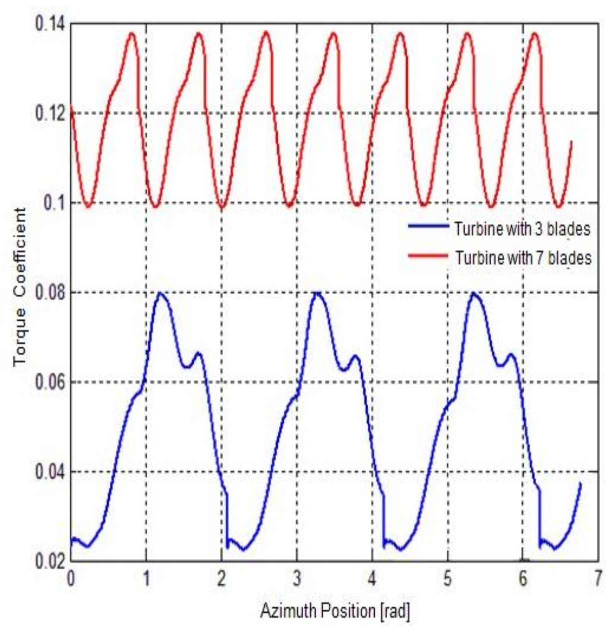


Fig.14 Dynamic simulation of two rotors with three and seven circular arc blades.

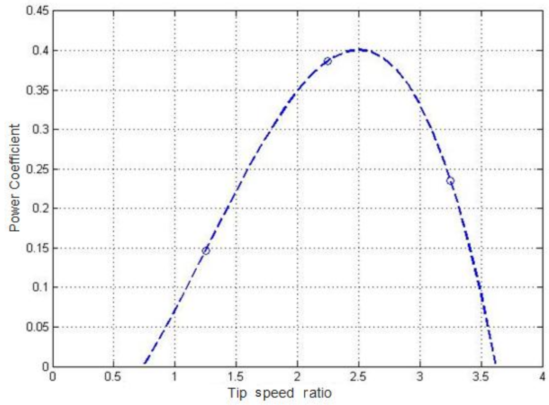


Fig.15 Variation of the predicted Power Coefficient of a hydrokinetic turbine as function of the tip speed ratio.

Further simulations were realized for a hydrokinetic turbine with seven blades of circular arc profile with chord length of 180 mm, radius of 500 mm and height of 1 m, submitted to a tip speed ratio of 2.5 with free water flow velocity of 2 m/s and it was found that the generated power is of about 1.6 kW or 4147 MJ/month, which is sufficient for 7 average Brazilian homes, fig.15.

The concept of vertical axis hydrokinetic turbine offers numerous possible installation schemes, possibility of incrementing the installed capacity, ease of repairing and maintenance with the possibility of transport to other hydraulic sites [1]. Various options for hydrokinetic turbine installation are investigated in the literature such as fixed on the bottom, floating and fixed near the surface. Two possible installation arrangements are shown in fig.16.

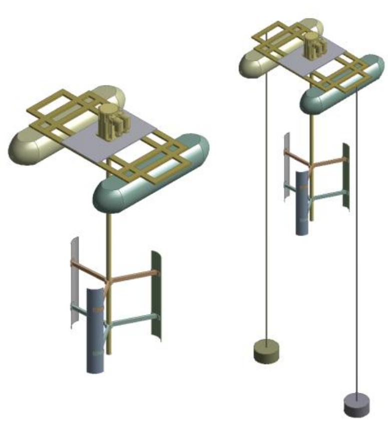


Fig.16 Two possible installation arrangements for hydrokinetic turbines.

VI. CONCLUSIONS

As mentioned before the main objective of the paper is to investigate a cheap hydrokinetic turbine for utilization in the Amazon rivers to guarantee access of the local isolated communities to electric energy. With this concept in mind two blades, that is flat plate and circular arc profiles were selected for investigation. These profiles are of simple geometry, can be easily manufactured and have analytic solutions. CFD simulations showed that circular arc profiles are more efficient and produce more power. Rotors with three, five and seven blades were simulated and it was found that the seven blades arrangement can produce about 1.6 kW enough for the consumption of seven average Brazilian homes. Some possible installation arrangements are also proposed. This preliminary investigation can be useful as a start for further work and decision making.

ACKNOWLEDGMENT

The authors wish to thank the CNPQ for the PQ Research Grant to the first author.

REFERENCES

[1] M. J. Khan, G. Bhuyan, M.T. Iqbal, J. E Quaicoe, 2009, “Hydrokinetic energy conversion systems and assessment of horizontal and vertical axis turbines for river and tidal applications: A technology status review”, *Applied Energy*, 86, pp. 1823-1835.
[2] A. Rachman, R. Balaka, J. Delly, “A Mathematical Model for Predicting the Performance of a Horizontal Axis River Current Turbine with Consideration of Blade Parameters”, ***Proceeding International Conference and Exhibition on Sustainable Energy and Advanced Materials***, Indonesia, 2011.
[3] K. Golecha, T.I. Eldho, S.V. Prabhu, 2011, Influence of the deflector plate on the performance of modified Savonius water turbine, Applied Energy, 88, pp. 3207-3227.
[4] A.R. Malipeddi, D. Chatterjee, 2012, Influence of duct geometry on the performance of Darrieus hydroturbine, Renewable Energy, 43, pp. 292-300.
[5] H. Zhen, D. Xiaoping, 2012, Reliability analysis for hydrokinetic turbine blades, Renewable Energy, 48, 251-262.
[6] K. Kanzumba, J. V. Herman, 2013, Hydrokinetic power generation for rural electricity supply: Case of South Africa, Renewable Energy, 55, pp. 467-473.
[7] W.C. Schleicher, J.D. Riglin, Z.A. Kraybill, A. Oztekin, Design and Simulation of a Micro Hydrokinetic Turbine, **Proceedings of the 1st Marine Energy Technology Symposium**, Washington DC, USA, 2013.
[8] N.K. Sarma, A. Biswas, R.D. Misra, 2014, Experimental and computational evaluation of Savonius hydrokinetic turbine for low velocity condition with comparison to Savonius wind turbine at the same input power, Energy Conversion and Management, 83, pp. 88-98.
[9] H. J. Vermaak, K. Kusakana, S. P. Koko, 2014, Status of micro-hydrokinetic river technology in rural applications: A review of literature, Renewable and Sustainable Energy Reviews, 29, pp. 625-633.
[10] A. C. Fernandes, A. B. Rostami, 2015, Hydrokinetic energy harvesting by an innovative vertical axis current Turbine, Renewable Energy, 81 pp. 694-706.
[11] N. Acharya, C. Kim, B. Thapa, 2015, Young-Ho Lee, Numerical analysis and performance enhancement of a cross-flow hydro turbine, Renewable Energy, 80, pp. 819-826.
[12] G. F. Cada, M. S. Bevelhimer, Attraction to and Avoidance of Instream Hydrokinetic Turbines by Freshwater Aquatic Organisms, Oak Ridge National Laboratory, 2011.
[13] G. Hagerman, M. Tidal “In-Stream Energy Conversion (TISEC): Survey and Characterization of Potential Project Sites”, EUA, 2006.
[14] J. Hardisty, “The Analysis of Tidal Stream Power”, John Wiley & Sons Ltd., Oxford, 2009.

[15] **L. Kuerten, M. L. Santos, A. Silva**, ***Variação das características hidro sedimentares e geomorfologia do leito do rio Ivai – PR, em seu curso inferior***, UNESP, São Paulo, 2009.
[16] M. Anyi, B. Kirke, 2010, Evaluation of small axial flow hydrokinetic turbines for remote communities, Energy for Sustainable Development, 14, pp. 110-116.
[17] M. S. Guney, 2011, Evaluation and measures to increase performance coefficient of hydrokinetic turbines, Renewable and Sustainable Energy Reviews, 15 pp. 3669-3675.
[18] J. Zanette, D. Imbault, A. Tourabi, 2009, A design methodology for cross flow water turbines, Renewable Energy, 35, pp. 997-1009.
[19] **R. E. Sheldahl, P. C. Klimas**, ***Aerodynamic characteristics of seven symmetrical airfoil sections through 180-degree angle of attack for use in aerodynamic analysis of vertical axis wind turbines***, Livermore, Sandia National Laboratories, 1981, 118p.
[20] K. A. R Ismail, T. P. Batalha, 2015, A comparative study on river hydrokinetic turbines blade profiles, Int. Journal of Engineering Research and Applications, 5, (Part -1), pp. 01-10, www.ijera.com.

Kamal A.R. Ismail, Master degree in Mechanical Engineering, "Fluid Machinery" in 1967 and PhD, in Aeronautical Engineering in 1972 from Southampton University, UK. Full Professor in Mechanical Engineering since 1980. Was the head of the post graduate school in mechanical engineering for more than 14 years, Dean of the Mechanical Engineering Faculty for four years, technical consultant for a good number of governmental establishments, private industry and others. Main research areas include Energy storage, Thermal Comfort, Heat transfer, Aerodynamics, Hydrodynamics and energy for isolated areas. Interested in Engineering education, innovative programs and experimental equipment for teaching engineering. Responsible for creating engineering courses in the areas of Energy, Aeronautical Engineering in the under graduate and post graduate levels. Author of 22 books in different engineering subjects in the area of interest, over 350 articles in journals and specialized conferences and congresses, author of more than 85 research projects, reviewer for more than 20 scientific journals and member of the editorial boards of three international journals.

Tiago P. Batalha, Mechanical Engineer, Master in Mechanical Engineering, Development engineer in Schaeffler, Brazil.

Fatima A. M. Lino, Master degree in Energy Planning and Ph.D in Mechanical Engineering, Pos-doctorate in Mechanical Engineering. Research areas of interest, Heat Transfer, Waste Management and Treatment, Waste-to-energy research. Co-author of 4 books in different engineering subjects in the area of interest, over 19 articles in scientific journals, six articles in specialized conferences and congresses and reviewer for 2 scientific journals.