

HYDROKINETIC PROPELLER TYPE TURBINE FOR THE ELECTRIFICATION OF ISOLATED HOUSEHOLDERS OR COMMUNITY AND SOCIAL END-USERS

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Abstract*. This paper presents a free-flow hydropower turbine, also known as a hydrokinetic turbine, designed to generate electricity using only the kinetic energy of water flow in rivers. This propeller type turbine was installed in the inland of Brazil to supply electrical energy for a small medical center. Initially the paper presents some efforts with hydrokinetic energy made by researchers in Brazil in the last two decades, presenting the state of the art in this field. Next, the theoretical framework for the use of hydrokinetic energy is presented with the boundary conditions for the maximum performance in rivers, along with the different configurations experimented to transform kinetic energy in mechanical power. The design of the turbine is presented and discussed, including the stator, the propeller, the mechanical transmission and the electronic control system.*
The developed technology proved to be robust and suitable for the extremely severe conditions of the remote and isolated villages, since it has been functioning uninterruptedly for the last eight years. This type of small hydrokinetic power turbine typically can provide up to 2 kW of electric power, being a reliable alternative for the electrification of remote and isolated householders, communities or social end-users.

Keywords*. Renewable energy, Hydrokinetic turbine, propeller, free flow turbine.*

1. Introduction

The use of kinetic energy of rivers can be considered one of the first forms men invented to transform natural forces into mechanical work. The use of river flow always has always been used in navigation and the waterwheel may be considered one of the most sophisticated mechanisms of the ancient times. Nowadays it is still common to find water pumps in the inland, driven with the use of waterwheels.

The technology to generate electricity from hydropower traditionally is done by the use of hydraulic turbines where the water is channeled through dams and tubes in order to use the water potential energy.

The use of kinetic energy is considered to be an alternative or a non-conventional form to generate electricity. It is a source of renewable energy supply.

This technology is an advance in respect to environmental impacts, due to the fact that it is not necessary to store potential energy in artificial lakes with the use of water dam, and so it consequently doesn't need to interfere with the natural course of rivers.

Most of the principles of this kind of turbine are derived from wind turbines, though its operation is similar.

2. Bibliographic review

The power which can be extracted from the kinetic energy obeys the law:

$$P = \frac{1}{2} \cdot K_b \cdot A \cdot \rho \cdot v^3 \tag{1}$$

where K_b is the coefficient of Betz (16/27 = 0,592) , A is the area, ρ is the density of fluid and v the fluid velocity.

This law was deduced in 1926 by Albert Betz to calculate the kinetic energy of wind, where he showed that only 59 percent of the total wind energy can be extracted to produce mechanical work with a wind turbine, and that this condition occurs only when the velocity of the flow which leaves the turbine is one third of the velocity that enters the turbine.

Hydrokinetic turbines can be classified in two types. The first is the vertical axis with its rotating axis perpendicular to the water flow. The second is the axial turbine with its rotating axis in the direction of the flow.

Souza (1999) makes a reference to hydrokinetic turbines for the generation of electrical energy which he denominated "Low head hydraulic unit with hydraulic hydrokinetic turbine". In this article Zulcy analyses the characteristics of vertical axis and axial turbines and shows that the power per unit is typically up to 2 kW for water velocities of 0,6 to 1,5 m/s.

Vertical axis turbines are preferred when it is necessary to take advantage of kinetic energy of flow that can have its direction changed, such as, for example, tidal systems. These turbines are so designed that the direction of rotation is always the same, independently of the direction of flow.

One of the first patents of these kind of turbines was issued to Georges Darrieus in 1931 (Darrieus, 1931). He invented a turbine having its rotating shaft transverse to the flow and blades with a streamlined section analogous to that of the wings of birds.

The concept of the turbine developed by Darrieus suffered some modifications. In 1995 this conception was optimized by Alexandre Gorlov, (Gorlov, 1991) who mounted the blades in a helicoidal form, obtaining with this more uniformity in its functioning.

An axial type turbine was presented by Corren (1986) for the generation of electricity, where the entire turbine is mounted on a reinforced concrete base placed on the river bottom.

There are few references in the Brazilian literature about the use of kinetic energy to generate electricity. One of the first papers is a report of a prototype of a horizontal axis type turbine designed by the National Institute of Amazon Research (INPA), called "cata-água" (Harwood, 1985).

In this article Harwood described a 4 meter diameter multi-blade propeller type turbine which is anchored into the river to generate electricity. This equipment was experimented in rivers in the Amazon region with water velocities of 0,7 up to 1,5 m/s and proved to be functional. However in this project there was no protection against fluctuating debris, quite common in these rivers, limiting its operation only to experimental aspects. The mechanical transmission devices used in this system was made with chains and introduced significant losses, besides the fact of not being robust enough to support an intense working regime. (24 hours a day)

The Center of Research in Electrical Energy – CEPEL, (Nascimento et all, 1999) also made mention to hydrokinetic energy, by means of a water wheel adapted to generate electrical energy and an axial type turbine.

This first equipment, constructed in association with a national manufacturer of water wheels and the Federal University of Rio de Janeiro – COPPE, is 3 meters width and 2 meters in diameter. It was mounted on floaters and had to generate 3,5 kW with water velocity of 1,5 m/s. The equipment was placed in operation in the Pirapó river in the state of Paraná and with the placing of load, it was observed an accentuated reducing in the turbine rotation, blocking its functioning.

The second experience realized by CEPEL was done with a prototype of an axial turbine in reduced scale (5/1) with a two bladed propeller. With this prototype measures where made to evaluate the influence of a convergent mouthpiece at the entrance of the propeller. These measurements did not provide significant results in the variation of the water velocity at the entrance of the turbine and the variation of power generated as a function of the use of the mouthpiece.

A well succeeded experience with hydrokinetic energy in Brazil was developed by researchers from the Department of Mechanical Engineering from the University of Brasilia with funding from the Fundação de Apoio a Pesquisa do Distrito Federal – FAP-DF and Fundação de Empreendimentos Científicos e Tecnológicos - FINATEC. Since 1991, a group of researchers of this institution has been experimenting with diverse prototypes of vertical and axial turbines, as shown in Fig. (1).

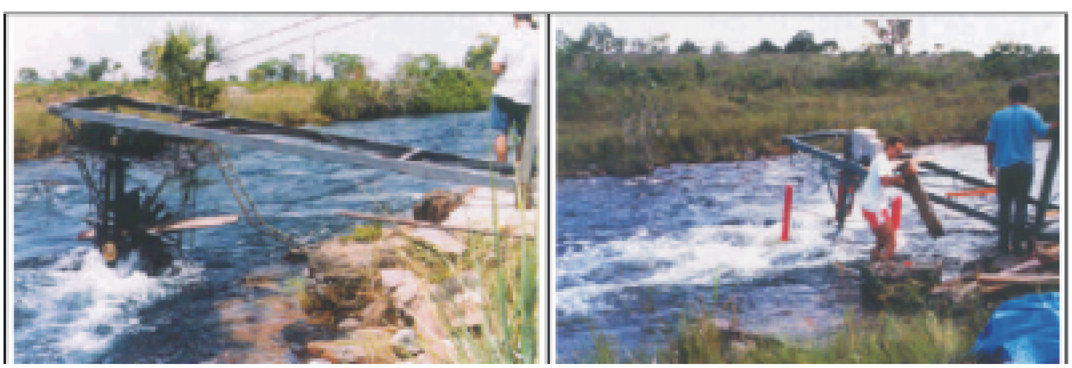

Figure 1. Prototypes of hydrokinetic turbines

These experiences produced significant data for the design of a hydrokinetic turbine which was placed in operation in 1995 and is functioning until now attending a small medical center in the inland of the state Bahia.

3. The axial hydrokinetic turbine

This project has some innovating features which where fundamental to improve the transformation of hydraulic energy in mechanical work.

Different from the projects presented by Souza, Harwood and Nascimento, the machine has a stator at the entrance of the propeller which directs the water flow in the turbine in such a way to increase the attack angle of the blades of the propeller, optimizing the transformation of hydraulic energy.

Another innovation is the use of a suction tube at the outlet of the turbine and the use of cones in the center of the turbine to minimize the generating of turbulence in the water stream.

The turbine is composed of a protecting grid (1), a stator with directing blades (2), a propeller(3), a suction tube(4) , cone for the incoming and outgoing flows(5) and a transmission box (6) as shown in Fig. (2).

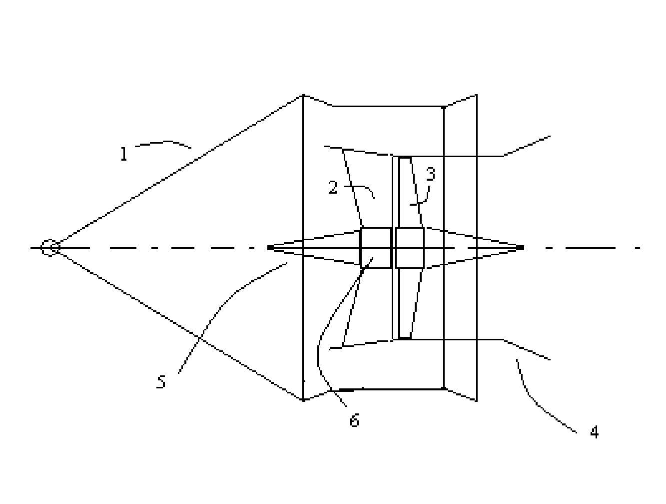

Figure 2. Turbine parts

The influence of the suction tube on the performance of the turbine was tested empirically in the field, and it was noted that there was a significant increment in the overall performance of the turbine with the suction tube.

Its important to emphasize that all experiments where made in the field, in the most extreme conditions of functioning and nominal load, without the ideal instruments to monitor all the variables of the process.

Two models of turbines where tested and installed as shown in figure 3.

Figure 3. Photos of the turbines

The rotor or propeller is composed of various blades. Experiments where made, manufacturing the blades with metallic strips and also with metallic structure involved with fiber glass. The number of blades, the transversal area and its coefficient of solidity depends on the river flow.

Figure 4. Some propellers tested

The best results for this turbine were obtained in river with a 1.8 m/s speed and a six blade, eighty centimeter, diameter propeller with a solidity coefficient of 50%.

The mechanical transmission system is implemented with a set of gears submersed in oil and a stage of transmission belts. The turbine is driving a 2 kVA, 220 volts AC electrical generator in 1800 rpm, generating 1 kW of electricity and making possible the use of a refrigerator, a freezer, a water pump and lightning.

To control the voltage and the frequency generated by the turbine, which in this case tends to vary with the water velocity and the load coupled on its grid, an electronic control system was designed. The control system maintains the electrical load on the grid constant in order to stabilize the grids voltage and frequency. This over voltage protecting system, based on a 1 kW thyristor driven resistance, makes it possible to couple conventional domestic electronic equipment on the grid.

4. Conclusion

The hydrokinetic turbines presented in this paper are functioning, producing stable electrical energy in 220 volts AC permitting the use of normal domestic equipment.

The innovations implemented in the design of the turbine were tested empirically in the field and proved to increase the overall performance of the system.

With these data it is possible to optimize the design of the turbine with the use of computational simulation and laboratory testing.

The developed technology proved to be robust and suitable for the extremely severe conditions of the remote and isolated villages, since it has been functioning uninterruptedly for the last seven years. This type of small hydrokinetic power plant typically can provide up to 2kW of electric power depending on river characteristics, being a reliable alternative for the electrification of isolated householders, communities or social end-users.

5. Ackowledgement

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