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Pico Hydro for power generation with Small-scale hydroplants

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Abstract:*Pico Hydro is a concept used for small-scale hydroplants for power generation under 5 kW. Small turbines of 200 to 300 W can supply a specific demand, such as a lamp, circuit, sensor, and others aplications. Pico Hydro generally occur in the flow, without the presence of a reservoir. Pipes divert the flow directly to a small turbine before being exhausted. This paper is the projection of a system to capture rainwater for the generation of electric power in small devices, consumable questioning – if your income. It is a system of great importance, as well as take advantage of a natural phenomenon, will be generating clean energy that can be reused on another device. The Project was based on a study of Turbine Michell – Banki, which turns water motion into mechanical work. The system was developed in three stages: theoretical calculations, the mounting system (simplified), and practical tests with water and the electronics part. The estimates were prepared with a theoretical basis in commercial product catalogs, enabling a functional simulation with the real prototype, but with a focus on the electrical system, eliminating the presence of water. The set is not yet able to provide useful energy volumes in small devices, showing relatively low yield. The individuality of the analyzed system undermines the results, which can be elevated with the multiplication of generators and capacitors, depending on the demand for energy needed to fuel a specific device.*

Keywords:*Pico Hydro, Small-scale hydroplants, Bánki turbine.*

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I. INTRODUCTION

Brazil being a country that faces situations of scarcity, it is still one of the most privileged concerning water [1]. Again, not everyone values this resource, few recognize that it is necessary both for us and for the world and that it is of fundamental importance also for the generation of electric energy in the country, supplying more than 90 % of the population [2]. Therefore, this project compound a system for generating electric energy through the capture of rainwater, aiming at its use in small devices, something interesting to be implemented in our society, because, in addition to taking advantage of this natural resource and, after use, reuse it in other activities that do not require filtration, will be generating clean energy and can be used in additional equipment, such as, depending on the power generated, recharge a cell phone [3].

Micro hydro is a type of hydroelectric power that typically produces from 5 kW to 100 kW of electricity using the natural flow of water. Installations below 5 kW are called pico hydro. These installations can provide power to an isolated home or small community, or are sometimes connected to electric power networks, particularly where net metering is offered [4].

Based on this, the objective of this research is to develop this electric power generation system, aiming at a necessary performance to be used in small components. Having as specific objectives: initially, to know the basic concepts of electricity and hydrodynamics; specify the ingredients used in the assembly; simulate the functioning of the electrical system, as well as the system wholly based on analytical data; design the prototype, in addition to testing and verifying its operation.

II. LITERATURE REVIEW

The Bánki Turbine is a low-cost motor that transforms the energy from the continuous flow of water into mechanical work, thus transferring the energy obtained by mechanical into electrical energy if it's connected to a generator [5]. This turbine is used in small hydroelectric projects in falls from 1.5 to 80 m and powers up to 2000 kW [5]. The energy generation occurs due to the water force in contact with the turbine blades, rotating it and causing its assembly, called a rotor, to revolve around a passing axis throughout the structure [6]. The Bánki turbine is a thrust and crossflow turbine. Therefore, it consists of a guiding blade, through which water, coming from the adduction pipe, will make its way through the upper part, cross and pass through the lower propellers, having two contacts with the fluid - after the liquid has picked up momentum. When it is directed out of the structure, it flows into an escape channel [6].

For power generation, the plants, in short, are based on a large turbine. The turbine connected to a generator, and the generator is connected to an electric transformer [7]. The river water, stored in a large water tank (limited by the creation of dams to have greater height and water pressure when it comes into contact with the turbine), when passing through the gates, comes in contact with these large turbines that are there, that is, large machines, similar to a fan, however, with the propellers in a vertical shape [7].

When these turbines come into contact with the water, they generate a mechanical revolution movement that, due to the drop and pressure of the fluid, will transform this mechanical energy into electrical, since these turbines directly connected to the generator, where the coils are, being those energized, producing electricity. After the water comes out of the floodgates and performs this energy production process, it usually flows along the river [8].

Decentralized energy systems are essential for economic and social development [9], and small-scale hydroplants also contributes significantly to decentralization [10-11].

III. MATERIALS AND METHODS

Laboratory tests need theoretical numbers consolidated in practical procedures of accredited companies and concepts of Modern Physics. The present demand occurs with the construction of tables, built using Microsoft Excel software, which expresses the hydraulic and electrical system and the support of the system at a given height. The path taken by the water was the topic of the first data table, collected in technical catalogs of companies in the hydraulic sector and of pipes that manufacture products such as water tanks, pipes, and adapters. In the beginning, water tanks considered being proper and viable for the system, designed based on the NBR 14799, with a minimum of 100 L and a maximum of 1000 L [12].

Such capacities tried to be efficient for the project because they are easy to locate, both in technical and commercial catalogs, leaving the smallest industrial container and reaching a ceiling of 1000 to 1020 kgf of stored cargo when the most significant water tank is filled.The cited data were found in L (liters) and requiring conversion to m³ (cubic meters) for reasons of adaptation to the formulas. The catalogs also contained information such as mass (filled or empty), dimensions, and the recommended flange type, according to NBR 14800 standard for installing water tanks.

A water tank with 310 L capacity has a mass of 7.5 kg (empty and without lid) with a lid diameter of 1000 mm, bottom width of 730 mm, height with a top of 690 mm, and without 600 mm cover. The fluid outlet area is necessary to determine its flow, which is one of the objectives of this hydraulic step. The water outlet area in the system was determined by Eq. 1.

$$A = \frac{\pi d^2}{4} \qquad \text{Equation 1}$$

A = area (m^2).
d = diameter (m).
π = 3.1416.

The speed with which the water flows at the outlet is the second objective of this process. The water flows depend on the height of the fluid's drop, which in turn is connected to the lateral dimension of the container and the wall of the residence. The right foot (fence) has a height of 2.50 m, but the height of the water tank and the position of the generator to the ground ignored, leaving less than 1.60 m for the fall of the fluid. Thus, the speed determined by Eq. 2.

$$v = \sqrt{2gh} \qquad \text{Equation 2}$$

g = gravitational acceleration (m/s^2).
h = height of the waterfall (m).

The volumetric flow rate, as previously mentioned, is significant for a possible test if connected to a water tank. In this way, it is possible to determine the water flow per unit of time (Eq. 3).

$$Q = A \times v \qquad \text{Equation 3}$$

Q = flow rate (m^3/s).
A = area (m^2).
v = velocity (m/s).

The structures, when requested for some effort, need to be dimensioned, considering the material, the load, the resistant surface, and the safety adopted in the project as variables. This demand characterizes the condition of the container support with water. Considering the capacity of each type of water reservoir, it's possible to determine the force applied to the structure. The structure must be made of steel, with a safety factor to avoid unexpected accidents. The applied force obtained with Eq. 4.

$$F = P + \rho g V \qquad \text{Equation 4}$$

F = force (kN).
P = reservoir weight (kN).
ρ = specific mass (kg/m^3).
V = volume (m^3).

In addition to the force, it is necessary to determine the material of the support and the safety factor (K) so that, with this, it is possible to dimension the support supports. The allowable stress used for dimensioning consists of the quotient of the yield stress of the material, and the K, which is modifying in the calculations, can define the support by the Eq. 5.

$$a = \sqrt{\frac{F \times K}{\sigma_{esc}}} \qquad \text{Equation 5}$$

α = support side (mm).
σesc = yield stres (MPa).

The projections used in this project have the function of providing greater clarity to the functioning of the system, schematizing the flow that the water will travel, demonstrating standardized quota values, and serving as a visual resource replacing some unnecessary parts for the prototype. One of the projections used was that of the water tank, as the materialization of this item is not essential since the theoretical calculations aim to simulate natural conditions. The container built with Autodesk Inventor 2018 software used technical catalogs. The water tank support, previously mentioned, was developed with those values, considering a steel structure, with the height of a standard house. This whole set of parts was assembled and adding the pipes.

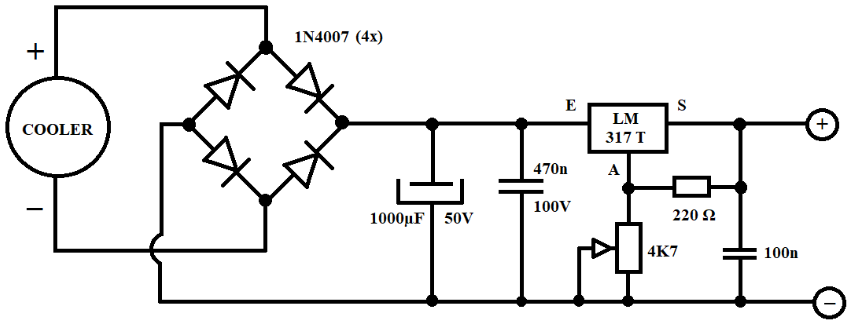
The electrical system maintained the standard, with the turbine present in the project, with real values to those found in the market. This system has cable output (positive and negative) that makes the connection with the circuit, which will be reported later. The turbine determined as ideal for the project is a more relaxed, housed in the Central Process Unit (in English, Central Process Unit - CPU), characterized by working with small voltages, low current, high speed, lightness, and small size. In terms of design, the 80 x 80 x 25 mm Cooler Chip Sce (code 075 - 8080) was adopted, with 12 V (Volts) of voltage (U) (Direct Current - DC, or English, Direct Current - DC), electric current (i) of 0.24 A (Amperes) and frequency of 2900 RPM (revolutions per minute).

The electrical circuit used for the energy generated, making it constant and capable of being used in devices that require steady voltage without many oscillations and adequate regulation for each situation. It is short and straightforward, with few components and easy to assemble. A rectifier bridge formed by four 1N4007 rectifier diodes, receiving alternating electrical current (sine wave) from the generator cooler through the bridge's positive-negative connections.

The rectifier sends through the positive-positive (resulting in the negative system connection), and negative-negative relationships (resulting in positive system connection), positive pulsating current. The “lines” assigned as positive and negative will make the rest of the joints and serve as support for the assembly of the components. Between these “lines” were placed three electrolytic capacitors of 1 mF (milli-Farad) for 25 V, which serve to make the pulsating current practically constant and stabilized.

The function of the adjustable positive linear voltage regulator is, as the name implies, to regulate the positive voltage and, therefore, it was necessary to be present in this circuit. This component has three terminals (E, A, and S): one that connects to the positive “line” (E or input); another related to the output of this “line” (S or output); and the last one linked to the potentiometer (A or adjust). The 4K7 potentiometer has the purpose of regulating the voltage that will come out at the end of the circuit, having a rotating pin for adjustment. It has three terminals: one that has already mentioned and the other two on the negative “line”. Finally, a 220 Ω resistor was used, connecting the outputs of terminals A and S of the regulator, to offer resistance to the passage of electrical energy, reducing the circuit current (Fig. 1).

Figure1. Electric circuit.



The assembly of the circuit executed with a universal electronic board, which has islands (holes) to facilitate the placement of each component. The input and output wires placed, allowing the projection of an acrylic box, with dimensions slightly more extensive than those of the assembled circuit, allowing the visualization of the electrical system.

The construction of a prototype occurred to collect the results, thus making it possible to know if the system is capable of being used in small devices. It was determined which parts would be necessary for the creation of the prototype, obtaining as an answer only the electrical circuit coupled to the generator system, discarding the water tank and its structure.

Theoretical calculations are essential at this point in the research to know the volumetric flow rate that a given container would have, thus being able to simulate such water flow. The option was to develop only the curve that leads to the generator and the pipe connected to the curve, which directs the water to a container on the ground. Initially, a cooler was disassembled to remove the magnet present inside the fan and the shaft attached to it, leaving a through-hole in the center of the generator, allowing the placement of a new shaft, but with greater length to reach the outside of the pipes.

The box that serves as the structure for the fan to rotate was cut from a square to approximately a circle, adapting to the shape of the pipes used. The surface was worked to obtain a better finish with a bastard file, perfecting the circumference. After that, a stainless-steel weld rod with coating was chosen as the axis of the system. However, it had a rod diameter of 3.30 mm, requiring machining to obtain 2.85 mm in diameter.

The set has three pieces in PVC pipes (Polyvinyl Chloride), all with a diameter of 100 mm (millimeters): a 45º curve (degrees); a glove; and a pipe approximately 300 mm long. The curve needed to be drilled for the shaft to pass, making the exact location of the hole very important, preventing vibrations. In this stage, the curve was supported on a steel prism to be stable and a square to check the component's perpendicularity and parallelism with the standardized table. The piece was crossed out with a height tracer, in order to find the axis on which the drilling should be made, and, using a ruler and square, the center of the hole was determined. The hole was drilled with a 4 mm diameter end mill, in the Yadoya drill - FY - A.50, with 1000 RPM revolutions and 200 grit sandpaper finish to avoid friction of the walls with the metal rod.

The set has three pieces in PVC pipes (Polyvinyl Chloride), all with a diameter of 100 mm (millimeters): a 45 º curve (degrees), a glove, and a tube approximately 300 mm long. The curve needed to be drilled for the shaft to pass, making the exact location of the hole very important, preventing vibrations. All measurements made with a Digimess caliper with 0.05 mm resolution and 150 mm capacity, and the remaining pipes were connected to the glove after the system finished assembling. Initially, the volumetric flow of one of the taps was determined, opening it a certain amount, and using a stopwatch and a 600 mL PET bottle. The time was marked from the moment it started to fill the container to the limit of the desired volume. I was using the eq. 6, it was possible to finish the flow.

Equation 6.

$$Q = \frac{\Delta v}{\Delta t}$$

Q = flow rate (m^3/s).
ΔV = volume variation (m^3).
ΔV = time variation (s).

From that moment on, practical tests started, placing the 45º curve under the tap, which was adequately open, allowing the internal fan to generate, transmitting revolutions to the axis, and, consequently, to the external fan. The electrical circuit was connected to the wires of the external cooler, using electrical tape, and marking the voltage generated with the multimeter at the other end of the set. The tests performed repetitively so that they could be measured several times for greater accuracy and being able to adjust, such as changing wires, tape, and electrical circuit.

IV. RESULTS AND DISCUSSIONS

The theoretical calculations showed results for speed and volumetric flow of the system, considering the conditions already described. The flow rate in a Fortlev 100 L water tank, for example, is $4.39x10^{-2}$ m^3/s, due to the small height for the fluid to fall, which also compromises the speed (flow variable), preventing higher values. The rate for the same container above is 5.59 m/s, reasonably good, but can still compromise the results of energy generation. A 310 L reservoir, giving another example, has a speed of 5.24 m/s and a flow rate of $4.12x10^{-2}$ m^3/s, showing how the values decrease with increasing capacity, which is inversely proportional to the parameters. This decrease, which can reach 4.81 m/s and $3.78x10^{-2}$ m^3/s, for a 1000 L container (higher capacity analyzed in the project), is explained by the height of the right foot of the residence, which has only 2.30 m, limiting the process. Among these numbers, it is still possible to see that the capacity does not directly influence the result, but the height of the water tank, which, in turn, subtracts from the height of the residence and offers a minimal drop height. The speed, as has been said, is right in these parameters. Still, with low capacity, it can result in a short period of execution of the water descent, generating considerable tension, possibly, but in the short term, reinforcing the inverse ratio relation between the factors. The pressure in the hole is relatively high, ranging from approximately 4000 to 8000 Pa (Pascal - N/mm²), however, due to the location of the hole, it can be said that the design of these water tanks has already been dimensioned for lateral shafts and certify possible outlets at the bottom.

The structure that should hold and suspend the water tank will be made of cast iron, with an allowable compression tension of approximately 80 MPa, resulting in a dimensioning for a 100 L container of roughly 3.60 mm square section. The choice of material was because it is often used in machine structures and bases, supporting high loads with excellent resistance when compressed.

The practical tests of the project prototype occur out in five different stages, but with the same methodology applied, obtaining some values as results of scientific research. Analysis occurred with the flow of the example, which has a speed of 5.24 m/s and a stream of $4.12x10^{-2}$ m^3/s, showing how the values decrease with the increase in capacity, this being inversely proportional to the parameters. This decrease, which can reach 4.81 m/s and $3.78x10^{-2}$ m^3/s, for a 1000 L container (higher capacity analyzed in the project), is explained by the height of the right foot of the residence, which has only 2.30 m, limiting the process. Among these numbers, it is still possible to see that the capacity does not directly influence the result, but the height of the water tank, which, in turn, subtracts from the height of the residence and offers a minimal drop height. The speed, as has been said, is right in these parameters. Still, with the low capacity, it can result in a short period of execution of the water descent, generating considerable tension, possibly, but in the short term, reinforcing the inverse ratio relation between the factors. The pressure in the hole is relatively high, ranging from approximately 4000 to 8000 Pa (Pascal - N/mm²), however, due to the location of the hole, it can be said that the design of these water tanks has already been dimensioned for lateral shafts and certify possible outlets at the bottom.

The structure that should hold and suspend the water tank will be made of cast iron, with an allowable compression tension of approximately 80 MPa, resulting in a dimensioning for a 100 L container of roughly 3.60 mm square section. The choice of material was because it is often used in machine structures and bases, supporting high loads with excellent resistance when compressed. The cost of cast iron is low and can be easily found on a large scale, without much expense and unique cost-benefit.

The practical tests of the project prototype happened in five different stages, but with the same methodology applied, obtaining some values as results of scientific research. Experiment 1, designed with a flow rate, does not generate any tension in the measurements and low fan speed. The flow, in this case, was much smaller than those calculated previously, and this may have resulted in zero stress in the tests. In experiment 2, the flow rate was changed to $6.83x10^{-5}$ m^3/s, generating no tension in the measurements and low fan speed. The flow, in this case, was much smaller than those calculated previously, and this may have resulted in zero stress in the tests. In test 2, the flow rate was changed to $1.89x10^{-4}$ m^3/s, as well as using the electrical circuit in a "spider" format, due to its assembly form, without a universal plate, generating up to 3.5 mV (millivolts). The next three tests take the same flow rate and increasing stress values, due to the form of assembly and measurement that have been improved. Tests 3, 4, and 5 obtained results of 12, 212, and 356 mV, respectively. This increase in the voltage generated occurred because the measurement method was improved, supporting an electrical circuit on an object. The terminals were accessible, and measuring the tension without the interference of human action in the contacts; by placing the 45º curve more inclined concerning the horizontal, simulating the real position of the prototype in the complete system, removing the wires that lengthened the wiring of the circuit with a universal plate, proving to be unnecessary and could result in more waste along the way, since they could be disconnected. The analysis is valid for the other sense as well, visualizing the reasons for having generated such a small tension in the millivolt house. One of these reasons is the use of capacitors with a voltage of 50 and 25 V, respectively, in the "spider" circuit. The one with universal plate, causing a delay in storing energy because they have so much voltage connected to a system that works at 12 V when properly connected, or even in millivolts, opening an extensive and distant range of values. The use of capacitors with voltage more focused on low-scale voltages could give better results; the vibration in the connection axis causes the movement to lose speed due to the friction generated with the hole walls in the 45º curve, making the generator move without having stability in the dynamics; the water flow was much lower than the calculated ones, with a smaller outlet diameter and lower speed, impairing the stream which, in the complete set, can be more than 200X (two hundred times) higher than that used in the tests.

V. CONCLUSION

This paper presented the development of this project with theoretical calculations to the projection, and creation of a prototype with practice tests that prove its viability. Furthermore, it is interesting to note that it is possible to make improvements in the valuable part of the system with the creation of shovels suitable for movement with water, thus having better use of energy, both mechanical and electrical, or reduce shaft vibration for better functionality between turbines. Regarding the electrical part, as shown in the results, reducing the number of capacitors in the current circuit or lower voltage capacitors, can improve the efficiency of the system, taking less time to carry out energy storage, as well as changing the existing cooler for a higher voltage. Therefore, there are many perspectives for improving this idea.

In view of the aspects presented, and although the results obtained were not expected to supply some small device, it is an idea with great potential for feasibility and functionality, because, in addition to generating energy from a clean source, the components for assembling the systems are low cost and can easily be found in the electronic market.

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