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Applications of Small Scale Renewable Energy

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Abstract: Promoting renewable energy technologies offers two advantages: energy diversification and the hope of development for poor and isolated communities that are not connected to electricity transportation and distribution grids. The power supply to isolated communities is conceived as support for productive, domestic, and commercial activities, and is considered as a strategic component within the framework for development. Within this context, small scale hydraulic machines that may be installed in different sites in the province of Córdoba, Argentina, and that may be fully manufactured locally, are being developed. This article describes the main characteristics adopted for the development and construction at the National University of Córdoba of two micro-turbines with Michell-Banki propeller. Simplifications adopted to make them technologically and economically accessible are also described.

Key words: microturbines; isolated generation; renewable energy; micro hydroelectric
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1. Introduction

Energy services have fostered economic development and improved living standards of the population, with positive effects on development.

There are many diverse marginal urban and rural areas that have problems with the power supply through conventional distribution lines, which leads to these people's lack of the benefits provided by electricity. Micro-hydros can be built by local staff and local smaller organizations, thus saving on the cost of the transmission lines.

There is high potential for renewable energy sources in Argentina. Among the main reasons for the lack of exploitation of micro-hydros are lack of access to reliable and low-cost technologies, the nonexistent local ability to assess, plan, design, and implement generation systems, the low level of confidence in sustainability of small systems in isolated areas, as well as the lack of national or regional policies and strategies that allow for its appropriated promotion, implementation and management.

Besides, small scale research is not common since power micro-generation is considered unprofitable.

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A few years ago, renewable energies (not considering large scale hydropower) were almost exclusively used by environmentalists and people who had no access to other type of energy, but gradually, it is becoming good business.

As we know, energy is converted and made with a very poor degree of efficiency (many heat losses). A thermal power plant (coal or petrol/oil) has 30% efficiency. In addition, transmission and distribution lines lose around 10%.

Successive losses of the transport and conversion chain make inefficient the use of energy generated in a place and transported to another. The best thing to do is to generate it in the same place it is used (generating for self-consumption) (Herrera Vegas, 2014).

In 1970, a turbine generating energy from natural gas required around 4000 kilocalories per kWh generated. Today, it requires 2500 kcal/kWh and with combined cycle (a series steam and gas turbine to make use of hot gases), it requires only 1500 kcal/kWh. But efficiency for thermal machines has physical intrinsic limits.

Efficiency is one of the indicators of the worth of a machine. Even the concept can be used for food: only an average of one unit out of 10 units of fossil fuel power used to produce food reaches the consumer's table as edible product. The rest is lost during production, transportation and distribution.

Efficiency in renewable energies may have other types of implications. A commercial photovoltaic cell has an efficiency of radiation conversion into electricity of 10 to 19% depending on its internal structure. And this has an impact on the surface necessary to be used in order to produce the same amount of energy.

In this regard, the use of hydroelectric power through micro-turbines has a great advantage: to allow the point where hydraulic energy is transformed into electric power to be close to the consumption points.

When intending to invest on energy sources, a comparison of alternatives is required. Since each energy source has a list of advantages and disadvantages, it is convenient to define numerical indicators that allow a more accurate comparison.

The following economic and environmental indicators that allow the analysis of different possible energy sources can be mentioned (Herrera Vegas, 2014).

- Cost per energy unit (financial cost)
- Environmental cost
- Energy payback time (cost recovery)

Regarding energy payback time, different repayment forms can be defined: the environmental and the financial one. The environmental approach is applied to non-polluting renewable energies. It is defined as the time necessary to compensate for the CO_2 emissions produced during the equipment manufacture and saved during its use. For example, a thermal solar generator (residential hot-tap water) is compared to a natural gas water heater. During the manufacture of a thermal solar device, a quantity of CO_2 equivalent to a natural gas water heater working for 1.5 years is generated.

2. Hydroelectricity

Hydroelectricity is a mature technology. Hydraulic turbines have global efficiencies of around 90%, at their highest efficiency point. This distinguishes them from other sources of energy.

What is new about hydroelectricity has to do with where to apply it, on which scale, and how to solve the problem the generation matrix, that is, how it is linked to other alternative energy systems.

However, its evolution has not come to an end; but instead it is being adapted to the needs for clean energy, since the sites available require more compacted turbines and works with smaller impact.

2.1 Hydroelectric Potential in Argentina

The national hydroelectric potential is partially exploited. Of the 170,000 GWh/year identified, only 38,000 correspond to plants in operation, intended plants, or plants under construction. The rest makes up a set of studies and projects in need of updating. The set of projects referred to includes a large number of small power plants (up to 15 MW) of great significance for local and regional development.

The total installed hydropower capacity was 9,735 MW in 2002, supplying 34,000 GWh of power during the same period. Within this total are included 675 GWh from around 60 small power plants with a total power that accounts for around 180 MW, including 20 micro and mini power plants that belong to several isolated rural power systems basically served by diesel generators (Renewable Energy Coordination - National Promotional, 2005).

3. Environmental Advantages of Micro-hydroelectricity

There is increased awareness on the environmental effects of the current economic development system, such as climate change, acid rain, and the hole in the ozone layer.

Modern societies, which sustain their growth on an energy system mainly based on power generation through fossil fuels, are more and more inclined towards the adoption of measures that protect our planet. This is mirrored in the current national policies and international agreements and treaties that include, as their main objective, sustainable development that do not compromise the natural resources of future generations (Castro, 2006).

Today, renewable energies are no longer minority and costly technologies and have become fully competitive and effective to meet the demand requirements. Among these renewable energies is hydropower energy, as the main ally in clean and native power generation.

In this context, hydropower generated with micro power plants offers advantages over other sources of energy:

- Availability: The water cycle makes it an inexhaustible resource.
- Clean energy: It does not emit greenhouse gasses, nor does it produce acid rain or toxic emissions.
- Inexpensive energy: Exploitation costs are low and its technological improvement facilitates the efficient use of the available water resources.
- It operates at ambient temperature. No refrigerating systems or furnaces, which use energy and generally contaminate, are needed.

4. Alternatives for Micro-turbines Use

Turbomachines are rotating machines that transfer energy between a fluid and a rotor fitted with blades, through which fluid passes (Polo Encinas, 1976).

Energy change is verified by a mutual action (action and reaction) between the walls of the blades and the fluid (Mataix, 2009).

Each type of turbine can only operate with flows between the nominal (for which performance is the maximum) and the technical minimum, below which it is not stable (Fernández Mosconi et al., 2003).

The flow and waterfall height define a point in the graph that encounters the operational envelope of each type of turbine. Any turbine within which its envelope meets this point, could be used for the design conditions. The final choice will be the result of an iterative process that balances annual energy production, the acquisition and maintenance cost, and reliability (Figure 1).

At the School of Exact, Physical and Natural Sciences of the National University of Córdoba, projects related to the design, construction and installation of micro-turbines are being developed, emphasizing accessibility of construction with local labor force without high level of specialization.

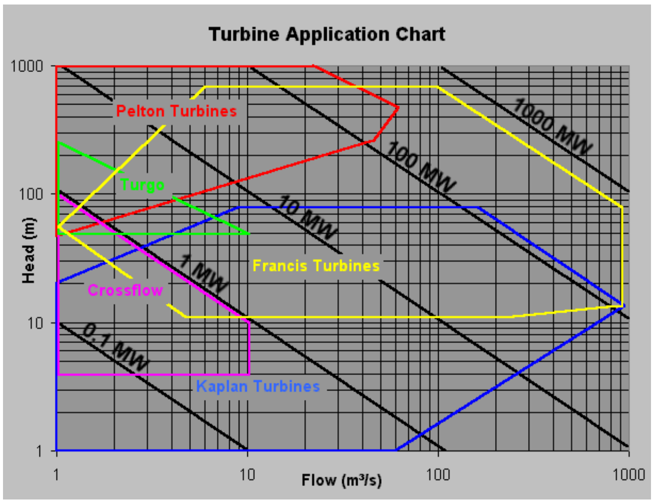

Figure 1 Classification of Turbines Depending on the Jump

Source: https://en.wikipedia.org/wiki/Water_turbine

There are two machines developed at the university:

The first is a Michell-Banki turbine on a scale of 1:1 installed at the University Hydraulics lab, on which numerical modeling of the blades was conducted to determine adjustments to the design.

The second one is a Propeller turbine. This turbine is currently in design adjustment stage and its construction will shortly start.

The design of both turbines was based on the selection of a model that could meet the requirements of high performance, and low manufacturing, installation, exploitation, and maintenance costs.

Installation and maintenance easiness for any user was considered in the design, so as to avoid the need of intervention of highly specialized labor.

The design considered the elements directly participating in energy transference: the runner and fixed-blade hub.

As for the runner, it is necessary to define its geometric dimensions, and the number and disposition of the blades.

For the fixed-blade hub, geometric dimensions and number and disposition of blades are also defined.

It is also necessary to define the accessory elements as the casing, bearings, and seals, among others.

The geometric dimensions of the casing are defined.

As usually done, the design takes the methods used for larger machines as starting point; these are then adapted to the particular needs of the area of hydraulic micro-turbines.

The intention is to create a low cost machine, from which optimal efficiency and duration is expected. Also, the goal is to increase the turbine performance and reduce manufacturing costs by optimizing the passage of fluid through the machine.

In the design of the hydraulic micro-turbines, the costs of manufacture and maintenance are essential and decisive.

This is why when projecting the machine, the specific manufacturing procedure for this type of equipment should be considered, so as to minimize manufacturing and maintenance costs.

Dimensional tolerances and surface roughness should be minimized, since this is small size equipment, where relative errors become significant.

This is of crucial importance when making the elements intended to convert hydraulic energy into mechanical energy. They need to be dimensionally accurate to the design and to have a surface finish (roughness) appropriate for the machine size, without neglecting the cost of the machine itself.

The materials that make up the turbine should be the appropriate ones to endure possible cavitation conditions as long as possible, which will be the period until the fault is detected. They should also meet resistance requirements they will be subjected to, loading that will be calculated below.

Finally, the elements should be made of easily weldable material.

5. Michell-banki Turbine

The Michell-Banki turbine is a machine classified as an impulse, radial input and cross-flow turbine. Mainly used for small hydroelectricity facilities, its major advantages are its simple design and easy construction, which make it attractive in the economic balance of a small scale exploitation unit [6].

The main features of this machine are the following:

- The rotational speed can be selected within a wide range of possibilities.
- It can operate within wide flow and height ranges without significantly varying its efficiency.
- The turbine diameter does not necessarily depend on the flow.
- An acceptable performance level is reached with small turbines.
- Flow and power can be regulated by means of an adjustable blade.
- Its construction is simple; it can be manufactured in small shops.

The cross-flow turbine is particularly appropriate for small flows, that is, for rivers that generally carry little water for several months.

The water energy is transferred to the rotor in two stages, the reason why the machine is also called double-flow turbine. The first stage delivers 70% of the total energy transferred and the second stage, around the remaining 30% (Figure 2). Finally, the water is restored by means of a discharge at atmospheric pressure (reaction ratio = zero).

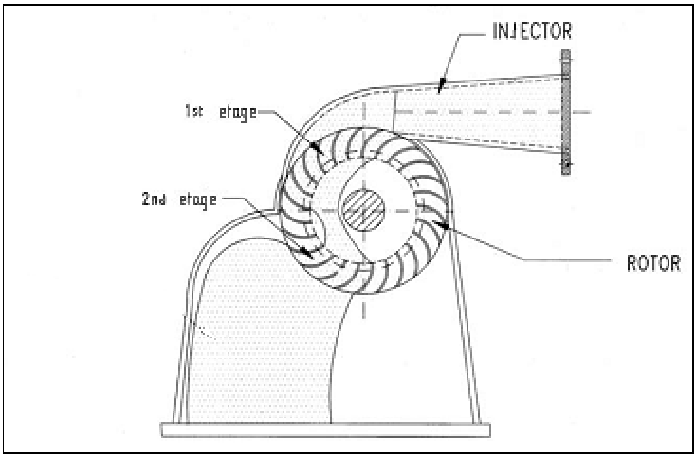

Figure 2 Schematic Turbine Constitutive (Góngora, 2012)

The turbine designed by the National University of Córdoba considers the following parameters: a 25.00 m effective waterfall; 0.120 m^3/s of flow to be carried by the headrace works. Considering 60% of performance, net output of 18 kW was reached.

The turbine consists of two main elements: an injector and a rotor. The rotor/runner has two parallel discs to which curved arch-shaped blades are attached.

The construction of the rotor and injector does not require high-precision casting tasks.

A very important element for the turbine's good operation and which generally requires high-precision construction is the blades. To facilitate this construction of the blades, carbon steel tubing with no seams was used. The pipe was cut forming an arch with θ angle, as shown in Figure 3.

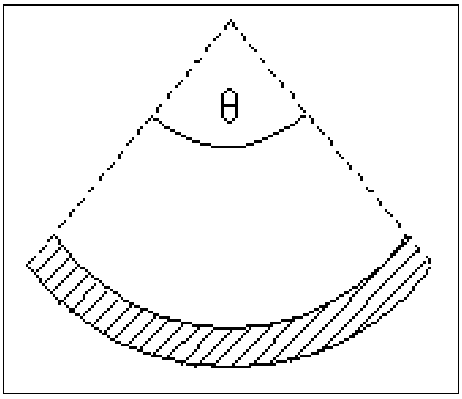

Figure 3 Cross-section of a Rotor Blade

For the construction of the different elements of the turbine, a series of tools, such as bending machines, shaping machine, milling machines, numerical control lathe, etc. were used. All the pieces that are in contact with water (rotor injector set) were subjected to a hot zinc surface treatment to extend their life span. Both the rotor and the injector were made of SAE 1020 steel.

Figure 4 shows the fully assembled turbine placed on a UPN profile frame; Figure 5 shows the Michell Banki turbine assembly drawing.

Figure 4 Michael Banki Turbine Completed

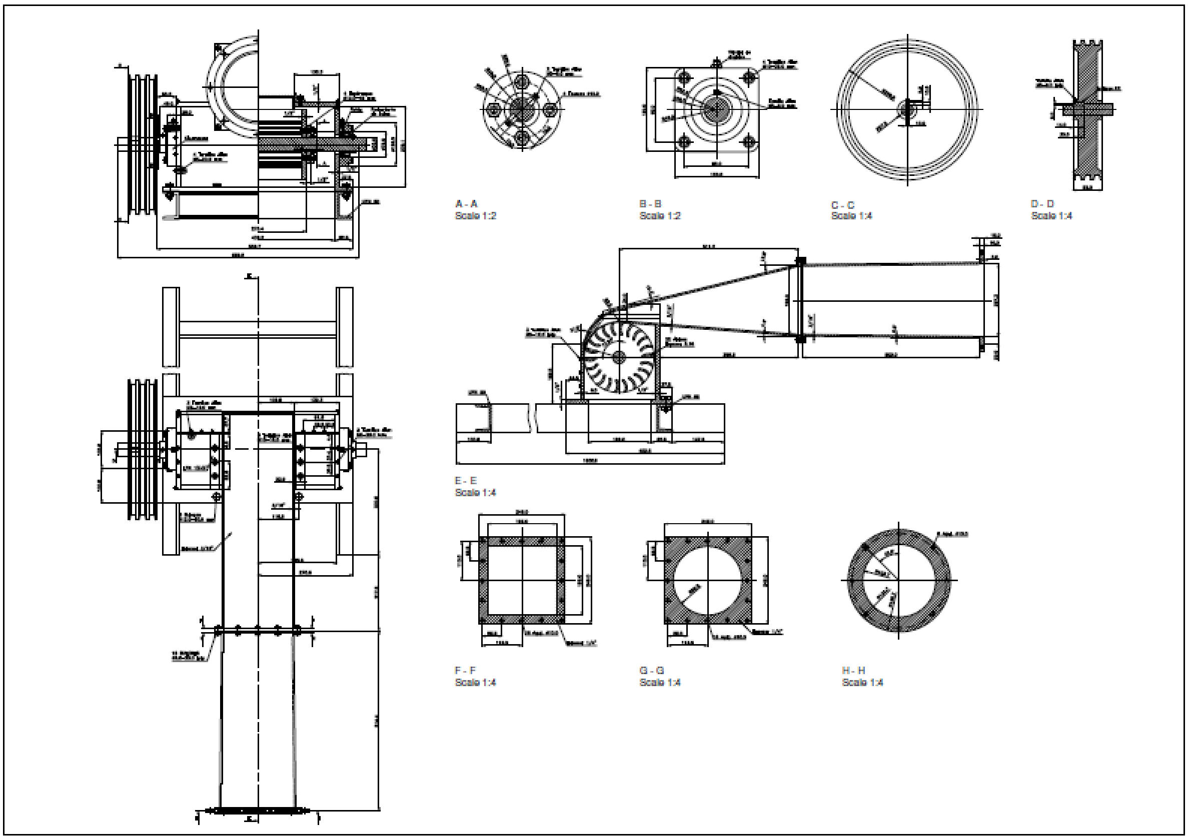

Figure 5 Michell Banki Turbine Projected

The project presented consists of a turbine of simple design and easy construction, which makes it attractive for small scale use.

6. Propeller Turbine

Propeller and Kaplan turbines in small waterfalls with higher flow rates are appropriate both in horizontal and vertical position.

The runner contains a few blades, which gives it the appearance of a ship propeller; when they are fixed, it is referred to as Propeller turbine, while if blades are adjustable, it is called Kaplan turbine; in both cases, the turbines operate with a single rotation direction; they are then, irreversible turbines.

The main features are:

- Compact dimensions.
- Relatively high speeds.
- High performance with variable head.
- Prominent capacity for overloads

The machine being developed at the National University of Córdoba considered a flow of 0.1 m^3/s and a net height of 5 m. With these values, considering approximate efficiency of 60%, we obtain an effective power of approximately 3 kW.

In these machines, the profile of the blades features hydrodynamic little curvature, which facilitates performance and increases fluid speed (water). Runner diameters are pretty small due to the above.

The rotor blades have an aerofoil blade section and helical development. The aerofoil blade section allows efficient action of water over the blade with respect to the movement of the first on the latter.

The helical shape or warp is justified because flow relative speed varies in direction and magnitude with radium, assumed constant ω (angular speed), and considering constant absolute speed in magnitude and direction.

Besides, blades are required to have a polished surface finish, since the allowed roughness between the contact surface and water depends on the flow rate.

This indicates that a study on the flow velocities that prevail should be conducted in order to give the blades the appropriate final finish. To this end, the turbine mathematical model is being carried out on the basis of the Solid Works software for the development of the different components (Figure 5).

Manufacturing the blades poses the main inconvenience for achieving an economical equipment alternative, since it requires precision casting.

Today, new alternatives are being studied, among which we find the construction of blades from a plate with cuts to the central diameter and then helically bended.

Choosing not to use aerodynamic blades but curved blades of constant thickness came to meet one of the main requisites of the possible use of propellers for micro-turbines, which is to be able to produce them in local workshops. This choice, regarding the blades, produce a lower lift coefficient and higher resistance, so that together the efficiency is less. It does not fully utilize the energy exchange from the fluid to impinge on the vanes, either. But the losses are not important if they are compared with the ease of manufacture and maintenance.

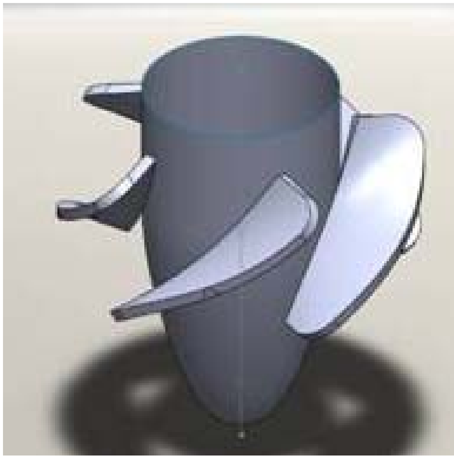

Figure 5 Rotor in Solid Works

The proposal is being studied, together with models, at metallurgical workshops in order to estimate its effect on the performance of the equipment.

The runner is preceded by the distributor, whose directional blades are generally movable; they are regulated during operation so as to achieve maximum performance. To simplify the design, the construction of a bended distributor with fixed blades.

As regards the characteristics of the possible materials that may be used to construct the blades, it is necessary that they have bending strength properties since water exerts a heavy load.

These requires the use of cast steel for small loads, low alloy steel for medium loads, and steels with 13% chromium and 1% nickel for heavy loads.

7. Conclusions

The advantages of micro hydropower plants distributed over the territory do not lie so much on the energy contribution to the national power needs, but rather on the value of using the resource in its electric conversion at a local level. Decentralized power generation alternatives and small power generation alternatives are still not significantly used to meet these demands, though in many areas there are natural resources that are easily exploitable with favorable economic, social, and environmental conditions.

Small-scale hydropower potential that is well supplied and located is economically competitive compared to the other renewable energy sources and, considering actual global cost, compared also to traditional energy sources. Micro hydraulic facilities account for a valuable energy form since with very low environmental impact, they use a renewable energy source.

Regarding the different types of machinery existing for the different hydroelectric plants, we can state that Michell-Banki and Propeller-type turbines are appropriated for the ranges of flow rates and falls available in the mountain sites of Córdoba and similar areas. They would solve the problems of electric power generation for isolated locations and for those locations that, due to low population density or distance to other towns, encounter difficulties in their interconnection to energy systems.

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