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Micro hydroelectric power: Feasibility of a domestic plant

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Abstract

The article presents the analysis of technical and economical feasibility of a small hydropower plant for domestic use (micro-hydro), how it can be implemented in Prignano sulla Secchia (MO, Italy). The necessary information and input regarding the duration of the discharge curve are reconstructed here through direct measures and indirect methods. Different solutions and combination of pipes and turbine and storage tanks have been analyzed in order to identify the most convenient. In particular the following alternatives have been considered: - systems with or without a storage tank; - the possibility of selling the produced energy directly to the network or using the energy for own consumption.

For each solution the yearly energy production was evaluated. Different scenarios were considered: cases in which produced energy is consumed directly or cases in which the produced energy is sold to the electric network through an exchange contract in place. No solution is currently depreciating rapidly (<5 years), but given the negligible investment, the cost of which is likely to grow, as well as incentive policies, we conclude that the potential for generation of electricity for own use and consumption is promising.

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Keywords: Mini hydro, Green energy; Domestic plant.

1. Introduction

The problem of resources supply and climate changes are recognized worldwide, despite the ratification of the Kyoto protocol [8]. Through this protocol, each participating state is committed to reducing emissions of pollutants, most responsible for climate change. This has led to and involves the use of incentive policies towards renewable energy sources. Renewable energy sources can produce energy without sacrificing natural resources. Demirbas [4] highlighted the role that hydropower currently

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has over other renewable sources like wind, solar and biomass, due to some key benefits of hydropower. This generally includes a lower cost of installation to equal installed capacity, higher reliability, energy production, and more intensity and consistency over time.

Hydropower is currently the largest renewable source at national and global level [9]. In 2005, in Italy, energy from hydropower plants has met 10.7% of the domestic energy demand and 72% of energy from renewable sources (Electrical Services Management,GSE [5].Currently, hydropower technologies in the field have reached full maturity and, after almost two centuries of exploitation, the industrial use of water resources has almost reached its technical limit [3]. In our country hydroelectric power plants have already been built in the last century and the water resources exploited and they are still in operation, thus confirming the renewability of the resource. Recent years have witnessed the reopening of old small plants, which previously were not economically feasible. In fact, nowadays, thanks to reduced fares offered to producers of renewable energy by the green certificates and the Convention "energy selling", and thanks to the lower costs of the electronic equipment which now have a lower impact on the overall budget in respect to the past, the hydropower plants can be an excellent source of economic gain also for small and medium size plants.

Although the conventional wisdom associated with the hydroelectric plants are primarily for large plants and equipped with reservoirs, hydropower production is a great use in systems of aqueducts and irrigation canals and water streams of small to very small [10]. These uses present no major innovations in hydroelectric power, but have begun to present itself in recent years as a possible direction of investment.

Since there is not always time to produce a flowing water system coinciding with that use, it has become common to connect the system to an electricity distribution network (e.g. [7], [1]). This makes the management of the plant better and easier but will incue the disadvantage of having to sell the energy to the national manager at the price imposed by them. These considerations apply to private hydropower plants in general but appear to be crucial in economic evaluations of systems, as in the case study discussed here.

In recent years for most of the Member States of the European Community, the purchase price of energy produced from renewable sources was set by national governments that. These governments became aware of the environmental benefits of these sources. The prices shall be adjusted by setting a guaranteed minimum. [11]. In Italy, as in other European countries, legislation is constantly changing. Currently, the reference standard for renewable energy installations is the decree on "stimulating the production of electricity from renewable sources", known as DM 18/12/2008, 24/10/2005 repealing decree, and establish the modalities for the implementation of new governmental incentives.

The aim of this paper is to evaluate the feasibility and affordability of a micro-hydroelectric power station (installed capacity less than 100 kW) for domestic use. In this study, the author has looked at a stream, informally named "Cunettone" that runs through the town of Modena Apennines Saltino. The paper aims to analyze different scenarios of economic and planning implementation enlight of changes introduced by recent legislation.

2. The study site

This study examines one of the smaller streams that cross the territory of Saltino, a tributary of the Secchia Prignano in the province of Modena, which is on the right side of the river Secchia. The stream in question has been the work of containment in the '70s as a result of large landslides that have affected the area, particularly the section that crosses the town has been contained by concrete steps. The channel width is about 60 cm (see Figure 1). The distance between intake and release area is 106.83 meters in a straight line and the vertical distance (head) equal to 25.31 meters (Figure 1).

Fig. 1. Study site. The intake is located at 360 m aswl and the turbine at 334 m aswl

In the section under consideration, the stream bed is made of concrete with a the regular trapezoidal form. This feature has suggested the adoption of a mobile, low cost fabricated metal box as shown in figure 2 as intake work.

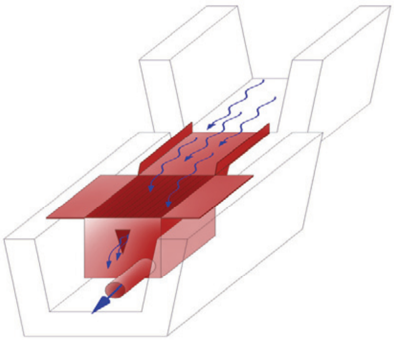

Fig. 2. Mobile, low cost metal box to be used as intake

With this design solution certain advantages can be achieved: - a limited environmental impact due to the fact that the intake does not require excavation and new construction work, it does not alter existing structures and can always be removed it to restore it to the initial state and any maintenance can be performed very easily

The storage tank is equipped with a weir that allows the measurement of excess water through turbines or in the case of machine breakdowns, the reading of the available flow. At the top of the tank is located a metal grid with the following protection purpose: to prevent any risk of injury to people or animals and to trap coarse debris transported by the current.

3. Water resources available

The feasibility study of a hydroelectric plant, even if small, needs information on the available water resources in order to assess the potential energy production of the plant. The flow duration curve of the stream is derived from the data published in the Italian Annals of hydrology. The problem can be solved directly, using the flow measurements performed in a section of the river, or stream from which to derive the water resource, or indirectly, using rainfall-runoff models based on data precipitation typical of the river basin.

In the absence of any data type on the basin under study or in absence of any information on the hydrology of the river "Cunettone", it was decided to carry out some flow measurements with a device properly made and calibrated for this purpose. The discharge measurements were performed by reading the level of a triangular weir, built on the wall of the mobile container. The maximum and minimum readable level allowed the flow rate measurement of 5 l / s and 0.5 l / s. The measurements were carried out once a day in the two periods: a) from 24 November to 22 December 2008 and b) from 8 February 2009 to 23 May 2009. At the end of the measurement campaigns, a sample of 134 discharge data was obtained.

In order to complete the sample to cover an entire year, an empirical model that allowed to reconstruct a relationship between rainfall-runoff was used. Results were validated with daily rainfall data recorded at the nearest available rain gauge, (Montefiorino approximately 10 km away from the river) and the corresponding measured discharge.

The flood hydrograph after the rain event recorded by the rain gauge on the 4th and 5th of March 2009 was forecasted. Details are described in Archetti et al., 2010.

From this analysis it was evident that the river collects water also from the soil, very important characteristics to guarantee the plan production also in more dry conditions

The described hydrograph was used to hindcast the water discharge also when direct data were not available but only rain data. The results are presented in Figure 3. The data covered the time period 18th of October 2008 to 23rd of May 2009; the summer period was nullified because the river discharges were lower than 0.5 l/s or they were too short for hydroelectric exploitation.

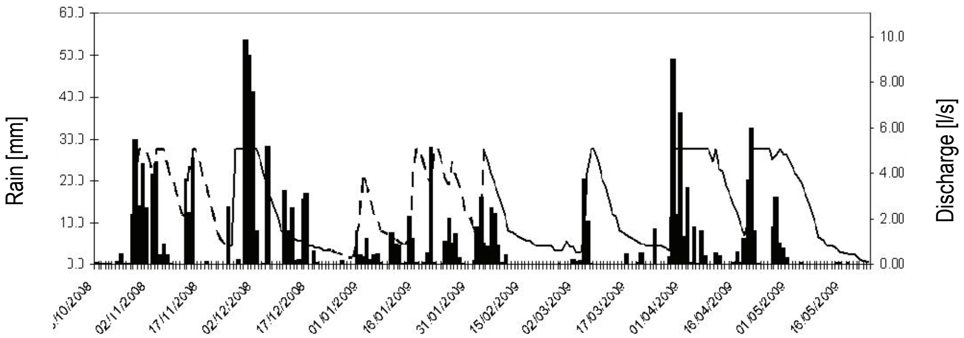

Fig. 3. Measured and simulated discharges: ▬in (mm at Montefiorino; ----- Measured Discharge (l/s); - - Estimated Discharge (l/s)

The flow duration curve (fig. 4) necessary for the feasibility of the mini hydroelectric plant is shown in figure 4.

4. **Design Hypotheses**

Many technical choices are dictated by the reduced availability of discharges supplied by the streams and consequently by the low power plant dimension. In particular, only the Pelton or Turgo types of turbines are able to work with a head of the size of the head of the plant here described [11]. In the plant design it was decided that polyethylene pipes would be used as they are suitable for the low values of discharges like the ones in the analyzed case. They are also used for water supply and agricultural irrigation systems. This choice was given by the low cost of these types of pipes and the relative ease of installation and low maintenance that they require.

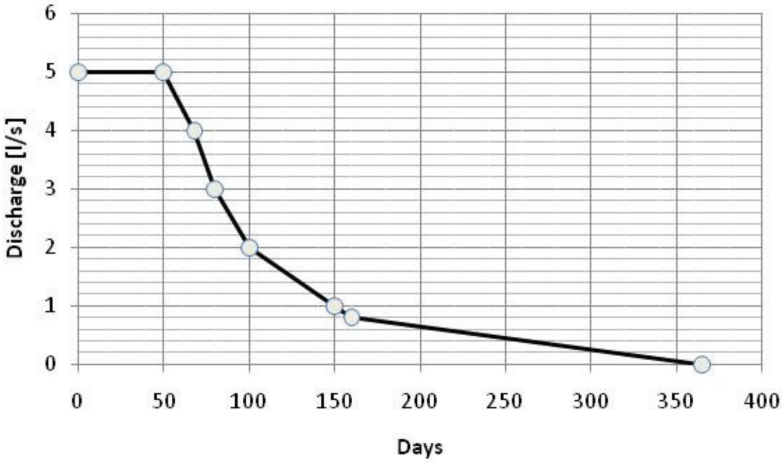

Fig. 4. Flow duration curve.

Different solutions and combination of pipes, turbine and tanks have been analyzed in order to identify the most convenient. In particular the following alternatives have been considered:

- systems with or without a storage tank;
- the possibility of selling the produced energy directly to the network or using the energy for own private consumption.

For each of the 4 design hypothesis (Table 2) the costs, the return and the depreciation length, have been estimated in order to establish the profitability of a domestic plant. The analysis of the first hypothesis is described in more detail and for the other three only the results are presented.

In the first hypotesis the plan exploit the available discharge flowing through a water system, using a Pelton turbine coupled to a permanent magnet generator that will power a DC inverter connected to the national electric grid. The feasibility study is analyzed considering the cost-effectiveness advantage of incentives on renewable energy sources (green certificates) through the agreement so called "selling to the network" which provides a fixed price of 0.22 euro per kilowatt hour produced. For each discharge- pipe diameters (D = 63mm,D=90 mm and D= 110 mm) combination, the net effective head was simulated, taking as input data the flow - duration curve in Figure 4. The maximum power retractable was finally calculated, the results are summarized in Figure 5. The energy was calculated by multiplying the power plant by the number of expected operating days per year. Of course, when the flow increases the the power increases but the days on which that discharge is available decreases. The maximum amount of energy produced can be obtained discharges values of 3 l/s 4 l/s for a diameter of 110 mm. In reality a pipe diameter (DN) D= 90 mm was chosen, because the advantages in terms of energy production for biggest diameters was too small compared to the higher cost of the plan construction with bigger pipes.

The second hypothesis of the project is the exploitation of available discharge through a plant, with a small storage tank with a volume of 2 m^3, to obtain a minimum discharge regulation to be sent to the turbine. It is planned to employ two Pelton turbines (one for a flow rate of 1 l/s and one for flow rate of 5 l/s) coupled axially to the same permanent magnet generator that will power a DC inverter connected to the national electric grid. In this scheme the turbine can generate energy more continuously then for the previous case. This scheme allows users to maximize the performance of the turbines but with more expensive construction costs.

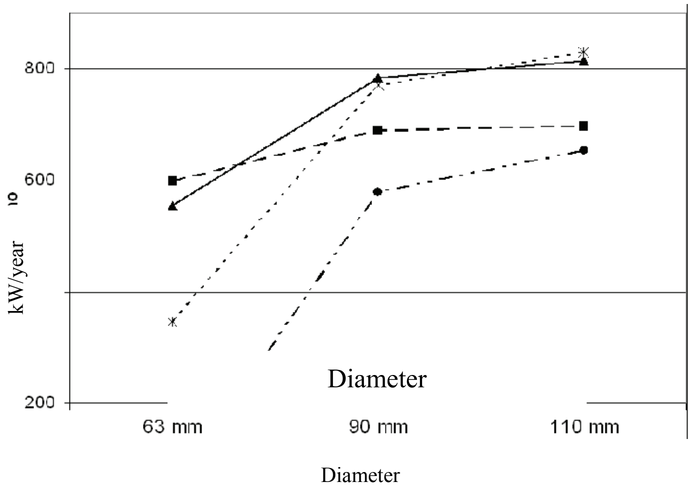

Fig.5. Energy resources with the first design Hypothesis. Discharges are: 1)■ 2 l/s; 2)▲ 3 l/s, 3) x 4 l/s and 4)● 5 l/s

In the third option of the project, the hydraulic plant as the same as the one in the first hypothesis, but the economic assessments are different: in fact it has been considered the tax benefits related to remodel with the purpose of saving energy. This type of solution is often used for small wind turbines where the low electrical power produced is used in order to reduce the amount of energy taken from the electric national grid. The final cost of electricity drawn from the national network for domestic utilities is, in fact, an average of 0.29 € per kWh which is higher than the price of the contract "selling to the network" considered so far. This is also because the cost includes various taxes and operating expenses.

The fourth hypothesis of the project considers to increase the head of the jump by placing the turbine / generator further downstream. The energy resource estimation is the same as the one presented in the first solution; additional costs for the rental of farmland have to be considered in the economic estimation.

5. **Costs and financial analysis**

For each of the 4 design hypothesis the costs, the economical return, the depreciation length have been estimated, in order to establish the profitability of a domestic plant [12], [13]. The costs are divided into initial costs for the construction of the plant (as an example are shown for the first solution in Table 1) and in yearly costs that include maintenance costs, estimated as € 35.00 / year and by the fee charged by the Manager of Electrical Services estimated as € 30.00 per year.

Table 1. Cost estimation for hypothesis 1

Description	Quantity	Unit cost	Total
			€
Turbine	1	150.00	150.00 €
Generator	1	450.00	450.00 €
Inverter	1	420.00	420.00 €
Polyethylene pipeline	120 m	5.42	650.00 €
Electric cable	150 m	0.36	54.00 €
Intake work		200.00	200.00 €

Description	Quantity	Unit cost	Total
Outflow works		150.00	150.00 €
Small building		200.00	200.00 €
Laying of pipeline	120 m	4.00	480.00 €
Eletric connection	1	150.00	150.00 €
			2904.00 €
	Taxes	20%	580.00 €
			3485.28 €

From a financial point of view the various options are compared according to the design parameters shown in Table 2, or for construction of the initial cost, annual net profit, return on investment, payback period.

Table.2. Synthesis of the annual net profit, return of investment for the 4 considered hypotesis

	Use of energy produced	Plant cost	Annual net profit	Return of investment	Amortization time
First hypothesis	Selling to the network	3485,28 €	229,14 €	6,5%	25 years
Second hypothesis	Selling to the network	4049,48 €	292,51 €	7,2%	21 years
Third hypothesis	Own consumption	3605,28 €	262,05 €	7,3%	8 years
Fourth hypothesis	Selling to the network.	4776,24 €	520,53 €	10,9%	12 year

6. Conclusions

In this work four design solutions for the production of hydroelectric power from a small river in the Italian Appenin have been analyzed and compared. The river discharges measured and estimated for one year, are modest (up to 12 l / s) but relatively abundant. In the design hypothesis, it was considered whether the energy produced can be consumed directly or it is transferred to the energy operator through the agreement "selling to the network". This is now possible thanks to the new laws for renewable energy.

The solution which results to be the most convenient, among the considered ones, is the third which plans to exploit the available flow flowing through a water system, using a Pelton turbine generator coupled with a permanent magnet direct current that powers an inverter connected in parallel directly to a house. The solution considers the tax benefits related to remodel, with the purpose of saving energy. With this solution the investment is amortized in eight years. This solution also appears to be even more independent of the technical solution, since it does not require agreements with the Manager of Electrical Services and is not subjected to the law on renewable energy, which can be subject to unpredictable changes. Despite the initial investment it is currently not convenient from a financial point of view, as the amortization time is very long. It is also true that in times of energy crisis, a hydroelectric plant that cost a few thousand euro, created in conjunction with broader work on upgrading the energy efficiency of a building for residential use, agrees with a view to environmental sustainability.

Moreover, considering that energy costs will likely to increase, then the payback period will decrease considerably, making the investment very profitable in the long run. Nevertheless, it is shown that the situation in which the building consumes all the energy produced shows already a good value for money. Finally, we can say that the technology of micro hydro is currently underdeveloped but that time is not yet fully ripe to consider a form of investment attractive to individual investors, who need to wait for a general increase in prices of ' energy and stabilization of incentive policies on renewable energy.

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