AN ECONOMICAL AND TECHNICAL CASE STUDY FOR A SMALL HYDROPOWER SYSTEM

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Abstract*:* *This paper presents a case study regarding the economical and technical parameters of a hydropower system for a mountain chalet - hotel. The calculations are made using RETScreen software starting from the average flow values of the considered river, and according to this, the hydro power plant equipments are chosen. In this case study the hydropower system is connected to central grid but also having its own storage backup system, part of the energy is consumed by the mountain chalet – hotel and the remaining energy is delivered to the central grid.*

1. INTRODUCTION

The environment pollution and energy crisis are the two most concerned problems around the world. In order to solve these problems, renewable energy was developed to replace part of the energy supply as an alternative for replacing classical fuels. Therefore, renewable energy is the second contributor to the world electricity production. Most of the electricity generated from renewables comes from hydropower plants followed by other renewables including: biomass, solid waste, geothermal, solar, wind, tide, and others. [5] Hydroelectricity is one of the most mature forms of renewable energy, providing more than 19% of the world's electricity consumption from both large and small power plants. Small-scale hydropower is one of the most cost-effective and reliable energy technologies to be considered for providing clean electricity generation. It is also environmentally benign. Small

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hydro is in most cases “run-of-river”; in other words any dam or barrage is quite small, usually just a weir, and little or no water is stored. Therefore run-of-river installations do not have the same kinds of adverse effect on the local environment as large-scale hydro (they do not have negative effects to the environment such as replacement of settlements, loss of historical sites and agricultural fields, destruction of ecological life). [12]

Each hydro site is unique, since about 75% of the development cost is determined by the location and site conditions. Only about 25% of the cost is relatively fixed, being the cost of manufacturing the electromechanical equipment. The development of small hydro projects typically takes from 2 to 5 years to complete, from conception to final commissioning. This time is required to undertake studies and design work, to receive the necessary approvals and to construct the project. Once constructed, small hydro plants require little maintenance over their useful life, which can be well over 50 years. Normally, one part-time operator can easily handle operation and routine maintenance of a small hydro plant, with periodic maintenance of the larger components of a plant usually requiring help from outside contractors. [1]

Although there is no universally agreed definition for ‘‘small hydro’’, the upper limit varies between 2.5 and 25MVA and a maximum of 10MW is the most widely accepted value worldwide. The terms mini- and micro-hydro are also used to refer to groupings of capacity below the ‘‘small’’ designation. Generally in industrial terms, mini- and micro-hydro typically refer to schemes below 2MW and below 500kW, respectively. These are arbitrary divisions and many of the principles involved apply to both smaller and larger schemes. [4]

Small hydropower systems allow achieving self-sufficiency by using the best as possible the scarce natural resource that is the water, as a decentralized and low-cost of energy production, since they are in the forefront of many developing countries. In Europe the development of small hydroelectricity grows up since the seventy decade, essentially, caused by the world energy crisis, and the concerns of negative environmental impacts associated to the energy production. Hydropower is the most important energy source in what concerns no carbon dioxide, sulphur dioxide, nitrous oxides or any other type of air emissions and no solid or liquid wastes production. The introduction of innovative solutions coupled to renewable energy technologies should contribute to a substantial global reduction in emission of CO2 and other gases, which are responsible for greenhouse effects. The hydroelectric power plant utilizes a natural or artificial fall of a river and enhances the main advantages comparing with other electricity sources, namely saving consumption of fossil, fuel, or firewood, being self-sufficient without the need of imported components. [11]

Hydroelectricity is now recognized as key technologies in bringing renewable electricity to rural populations in developing countries, many of whom do not have access to electric power. [7] Typically, small hydro generation is located close to the end-user which reduces or eliminates transmission losses and it gives independence from the world’s fossil fuel fluctuations. [6]

2. DESCRIPTION OF SMALL HYDROPOWER SYSTEM

A hydropower system has the following mechanical and electrical components: a water turbine that converts the energy of flowing or falling water into mechanical energy that drives a generator which generates electrical power, a control mechanism to provide stable electrical power and electrical transmission lines to deliver the power to its destination. [2]

Hydropower systems use the energy in flowing water to produce electricity or mechanical energy. Although there are several ways to harness the moving water to produce energy, run-of-the-river systems, which do not require large storage reservoirs, are often used for microhydro, and sometimes for small-scale hydro, projects. For run-of-the-river hydro projects, a portion of a river's water is diverted to a channel, pipeline, or pressurized pipeline (penstock) that delivers it to a waterwheel or turbine. The moving water rotates the wheel or turbine, which spins a shaft. The motion of the shaft can be used for mechanical processes, such as pumping water, or it can be used to power an alternator or generator to generate electricity. This fact sheet will focus on how to develop a run-of-the-river project. [8] In fig. 1 is presented a functional scheme of a small hydropower

The amount of power available from a hydropower system is directly related to the flow rate, head, the force of gravity and a efficiency factor. The theoretical power output (in kW) can be calculated using the following equation:

$$P = Q \cdot H \cdot g \cdot e \tag{1}$$

where:

Q = usable flow rate (m^3/s);

H = Gross head (m);

g = Gravitational constant (9.8 m/s^2);

e = efficiency factor (0.5 to 0.7).

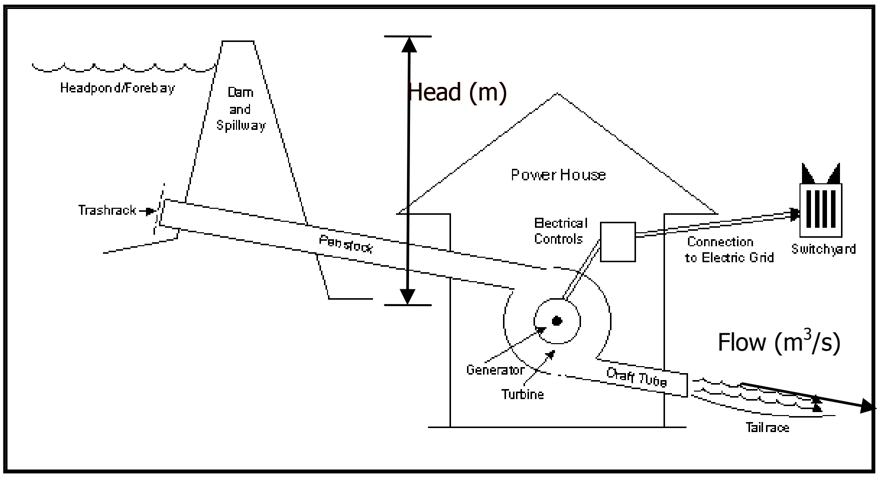


Fig. 1 - Small Hydro System Description

There are two types of turbines, impulse and reaction. For each application the turbine is chosen depending on the head and flow available. In table 1 we present different types of water turbines. [2]

Table1. Transposing principle

Turbine runner	High head (more than 100 m)	Medium high (20 to 100 m)	Low head (5 to 10 m)	Ultra-low head (less than 5 m)
Impulse	Pelton Turgo	Cross-flow Turgo Multi-Jet Pelton	Cross-flow Multi-Jet Pelton	Water wheel
Reaction	-	Francis Pump-as-turbine	Propeller Kaplan	Propeller Kaplan

The ‘capacity factor’ is a ratio summarizing how hard a turbine is working, expressed as follows:

$$capacity\ \ factor\ (\%) = \frac{energy\ \ generated\ \ per\ year\ (kWH/\,year)}{installed\ \ capacity\ \ (kW)\cdot 8760\ \ hours/\,year} \qquad (2)[3]$$

Generators convert the mechanical (rotational) energy produced by the turbine to electrical energy. There are two types of generators: synchronous and asynchronous. Synchronous generators are standard in electrical power generation and are used in most power plants. Asynchronous generators are more commonly known as induction generators. Both of these generators are available in three-phase or single-phase systems. [2]

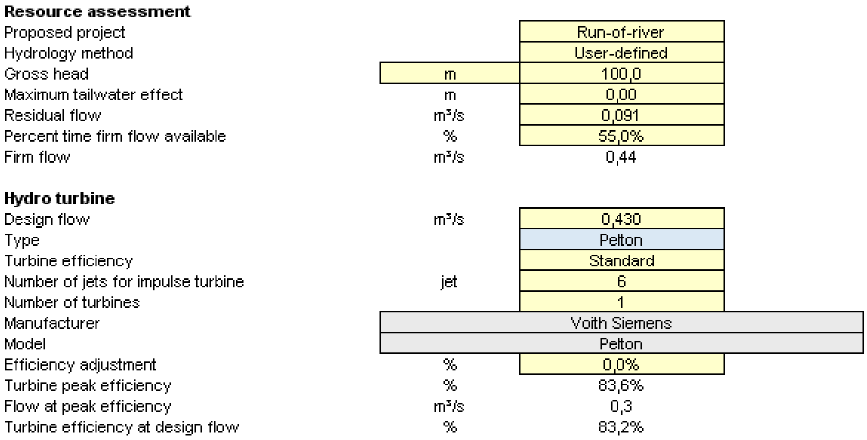
3. CASE STUDY AND RESULTS

The case study is for a mountain chalet - hotel with 30 rooms in a tourist area. The need for electrical energy is all over the year because the area has ski slopes in winter and rafting, climbing and other summer activities. The flow is from a real river but by economical reasons we can’t provide the name and the location of it. The analyze is made using RETScreen software which is a decision support tool developed with the contribution of numerous experts from Canadian government, industry, and academia. The software can be used to evaluate the energy production and savings, costs, emission reductions, financial viability and risk for various types of renewable energy.

The hydropower system is connected to central grid (20 kW) witch is located nearby. We chose to have backup batteries so we use synchronous generators and an inverter. We have made a list of consumers resulting the electrical power necessary for the building, the installed power P_i=70 kW.

The water intake location was chosen at the limit with the protected area so that we can obtain all the necessary approvals, the type of water intake is Tyrolean. The location where the power house will be located belongs to the owner of the mountain chalet – hotel. The distance between the intake and the power house is 2500 m resulting a head of 100 m. The connection between intake and power house will be made with an PAFSIN GRP adduction, with diameter D=600 mm and asperity e=0,03 mm. In calculating the diameter of the adduction the maximum hydraulic losses was considered 6,6%.

Knowing the head (100 m) and the design flow (0,430 m^3/s) we have chosen from product database a single impulse turbine, Pelton model, manufactured by Voith Siemens. (Fig. 2)

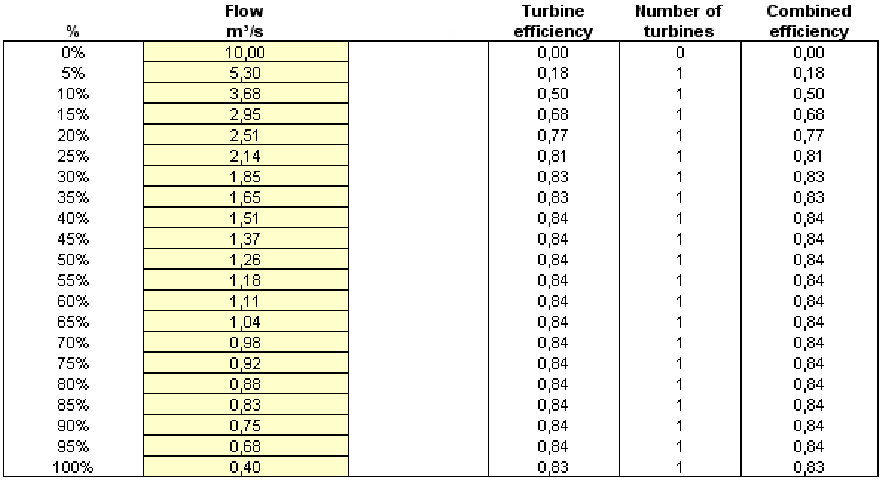


Resource assessment		
Proposed project		Run-of-river
Hydrology method		User-defined
Gross head	m	100,0
Maximum tailwater effect	m	0,00
Residual flow	m³/s	0,091
Percent time firm flow available	%	55,0%
Firm flow	m³/s	0,44
Hydro turbine		
Design flow	m³/s	0,430
Type		Pelton
Turbine efficiency		Standard
Number of jets for impulse turbine	jet	6
Number of turbines		1
Manufacturer		Voith Siemens
Model		Pelton
Efficiency adjustment	%	0,0%
Turbine peak efficiency	%	83,6%
Flow at peak efficiency	m³/s	0,3
Turbine efficiency at design flow	%	83,2%

Fig. 2 – Inserted data and results from RETScreen

After inserting the flow values in the program according to the hydro data achieved from Hydrological Institute (table 2), we obtained the following turbine efficiency curve (Fig. 3) and flow duration and power curves (Fig. 4) for that specific river. The firm flow (0.44 m^3/s) was calculated by the software after inserting the hydrological data and residual flow (0,091 m^3/s).

Table 2. Hydrological data and results for turbine efficiency and combine efficience



%	Flow m³/s		Turbine efficiency	Number of turbines	Combined efficiency
0%	10,00		0,00	0	0,00
5%	5,30		0,18	1	0,18
10%	3,68		0,50	1	0,50
15%	2,95		0,68	1	0,68
20%	2,51		0,77	1	0,77
25%	2,14		0,81	1	0,81
30%	1,85		0,83	1	0,83
35%	1,65		0,83	1	0,83
40%	1,51		0,84	1	0,84
45%	1,37		0,84	1	0,84
50%	1,26		0,84	1	0,84
55%	1,18		0,84	1	0,84
60%	1,11		0,84	1	0,84
65%	1,04		0,84	1	0,84
70%	0,98		0,84	1	0,84
75%	0,92		0,84	1	0,84
80%	0,88		0,84	1	0,84
85%	0,83		0,84	1	0,84
90%	0,75		0,84	1	0,84
95%	0,68		0,84	1	0,84
100%	0,40		0,83	1	0,83

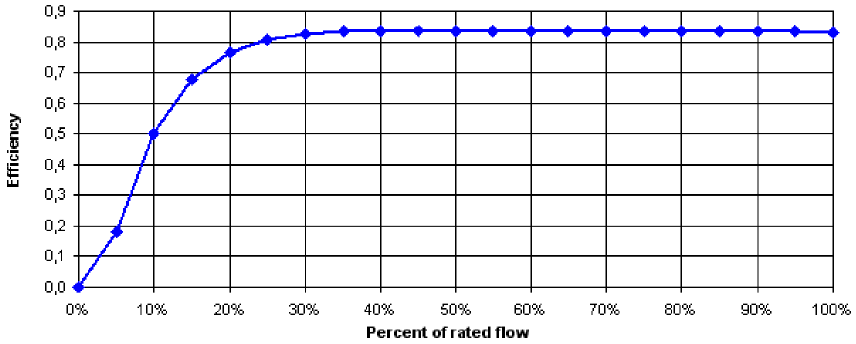


Fig. 3 – Turbine efficiency

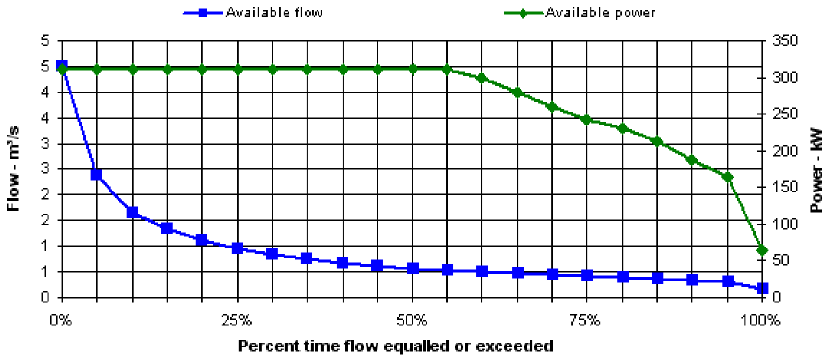


Fig. 4 – Flow duration and power curves

As it can be seen from the graph the turbine peak efficiency is 83,6% at a flow of 0,3 m^3/h. The generator efficiency is 95% and capacity factor is 88,2%. The power capacity resulted is 311 kW. The difference between the value obtained and the power needed for the hotel (approximately 240 kW) will be injected to the central grid. Considering that the area where the hydropower plant will be build is in continuous development, the extra energy witch is injected in the central grid, in the future, can be sold to other investors nearby.

The program also calculates the greenhouse gas (GHG) emission reduction witch was obtained with construction of this hydropower system. The net annual GHG emission reduction is equivalent with 1149 tCO$_2$.

The software estimate that the investment will be recovered in approximately 3 years for a project estimated life of 30 years (fig. 4).

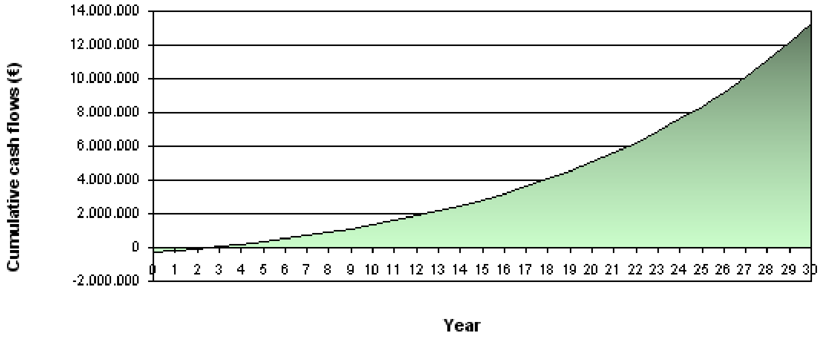


Fig. 4 – Cumulative cash flows graph

4. CONCLUSIONS

We have chosen an optimal positioning of the intake and power plant to obtain a maximum head. The Tyrolean intake is located on the main river, in the most concentrated area in terms of affluent rivers so we can take a higher flow, outside the protected area.

The optimal diameter for the adduction was chose for not having higher hydraulic losses. By using the PAFSIN GRP material for adduction because it has smaller asperity, we obtained a diameter of 600 mm, comparing with a steel adduction witch would be with 100 mm bigger.

The design flow was chosen smaller than the firm flow resulting a constant function of turbine during the entire year, considering that the river flow is variable and it also ensures the power needed for the mountain chalet – hotel. Even more, it provides profit by injecting the remaining power into the central grid.

The turbine will operate at maximal parameters about 60% of the year according to the graphics obtained through the RETScreen software.

Electricity production from hydropower has been, and still is today, the first renewable source used to generate electricity. Nowadays hydropower electricity in the European Union both large and small scale represents 13% of the total electricity generated, so reducing the CO2 emissions by more than 67 million tons a year.

The most important advantages that hydropower systems have over wind, wave and solar power are:

- a high efficiency (70 - 90%), by far the best of all energy technologies;
- a high capacity factor (typically >50%), compared with 10% for solar and 30% for wind;
- a high level of predictability, varying with annual rainfall patterns;
- slow rate of change; the output power varies only gradually from day to day (not from minute to minute);
- a good correlation with demand i.e. output is maximum in winter;
- it is a long-lasting and robust technology; systems can readily be engineered to last for 50 years or more.

RETScreen is a very useful tool for verifying technical and economical aspects for a hydropower system. Using this software we were able obtain information that this hydropower system can provide the necessary power needed for the hotel and also an estimated period for recover the initial investment.

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