DESIGN OF AN ENVIRONMENTALLY FRIENDLY SMALL HYDROPOWER PLANT IN THE ALIAKMON RIVER, GREECE

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ABSTRACT

Small hydropower plants are an environmentally friendly solution in order to generate power without flooding large areas and having negative ecological and social effects. However, small hydropower generation is often described as economically non-viable even with the rise of urgent environmental concerns. The Multi-Shaft Power Plant developed at the Technical University of Munich is an innovative solution that combines economical profitability and ecological aspects.

The purpose of this paper is to present first results of a pre-design study of a Multi-Shaft Power Plant in Aliakmon River. The assessment of potential locations for hydropower development is based on several criteria such as river slope, road and urban infrastructure, distance from cities, land uses etc. Moreover, an important factor that is taken into account is that the greatest part of Aliakmon hydro-system is already being exploited by existing large or small hydropower plants. Polydendro is selected as the optimum location for the construction, away from the existing plants. In this location, the design of a small Hydropower Plant has already been proposed and designed.

Three shafts are used for a design discharge of 45 m^3/s and a rated head of 9 m. The proposed Hydropower Plant has an installed capacity of 3.20 MW and a gross generation of 11 GWh/year. Moreover, fish migration in both flow directions is ensured via the design of a vertical slot fish pass to facilitate the upstream migration, whereas the downstream migration is facilitated by openings in the sluice gates with the overtopping flow.

The investment and O&M costs were estimated equal to 6.4×10^6 € and 175.64×10^3 €, respectively, while the yearly income of the project from Certified Emission Reduction was calculated equal to 2184 €/year. Taking into account the above mentioned costs and that the Feed-in Tariff is equal to 9.0 €/ 100 kWh, the project lifetime is 70 years and the construction period is 2 years, the Internal Rate of Return analysis showed that the project could start being profitable after 8 years for the base case scenario.

Keywords: Multi-Shaft Power Plant, environmentally friendly, small hydropower plant, economic profitability, ecological aspects.

1. Introduction

Greece has experienced a very severe financial crisis in the last years; moreover, EU policy is urging Greece to decarbonize its lignite-dominated electricity production possibly via the construction of new Hydropower Plants (HPPs).The economically exploitable hydroelectric energy potential is quite high; however, only 40% of it has already been exploited by 2013, due mainly to the dilemma that has been raised between the construction of large or small dams; the conventional large HPPs have severe environmental and social impacts, whereas small HPPs are more easily integrated into local ecosystems, when properly designed. However, the ERoEI (Energy Returned on Energy Invested) of small HPPs is almost half of the ERoEI for large HPPs

(Knapp, 2013). Consequently, it is hard to finance small HPPs as they are less economically viable than larger ones. A solution to this problem could be the Multi-Shaft Power Plant (MSPP), which has been developed in the Institute of the Hydraulic and Water Resources Engineering of the Technical University of Munich to combine economical profitability and ecological aspects. In this work, the possibility of implementing a MSPP in Aliakmon River is investigated at an entirely preliminary level.

2. Identification of potential locations and selection of the optimum

Aliakmon is the longest river in Greece, which is located in Western Macedonia. Four large HPPs (Asomata, Sfikia, Polyphyto and Ilarion) are already in operation, one re-regulating reservoir exists in Makrochori and one relatively small HPP in Agia Varvara (Stefanakos and Rampias, 2009). To identify the possible locations for hydropower development, we search for regions with high river slopes (>4%) that usually allow large hydraulic heads, which also satisfy the following criteria:(1) easy accessibility to road and/or railway infrastructure (distances less than 1-2 km), (2) close proximity to towns and/or cities (distances less than 10 km), (3) close proximity to the existing electricity grid network (e.g. transformers and substations), (4) non-interference with existing or planned HPPs and other engineering structures, and (5) location in areas with proper land use and far from protected or environmentally sensitive areas, such as NATURA and forests. Firstly, GIS and other form of data were collected to formulate an ArcMap for the Aliakmon catchment area allowing the quantification of the above-mentioned criteria that is illustrated in Figure 1.

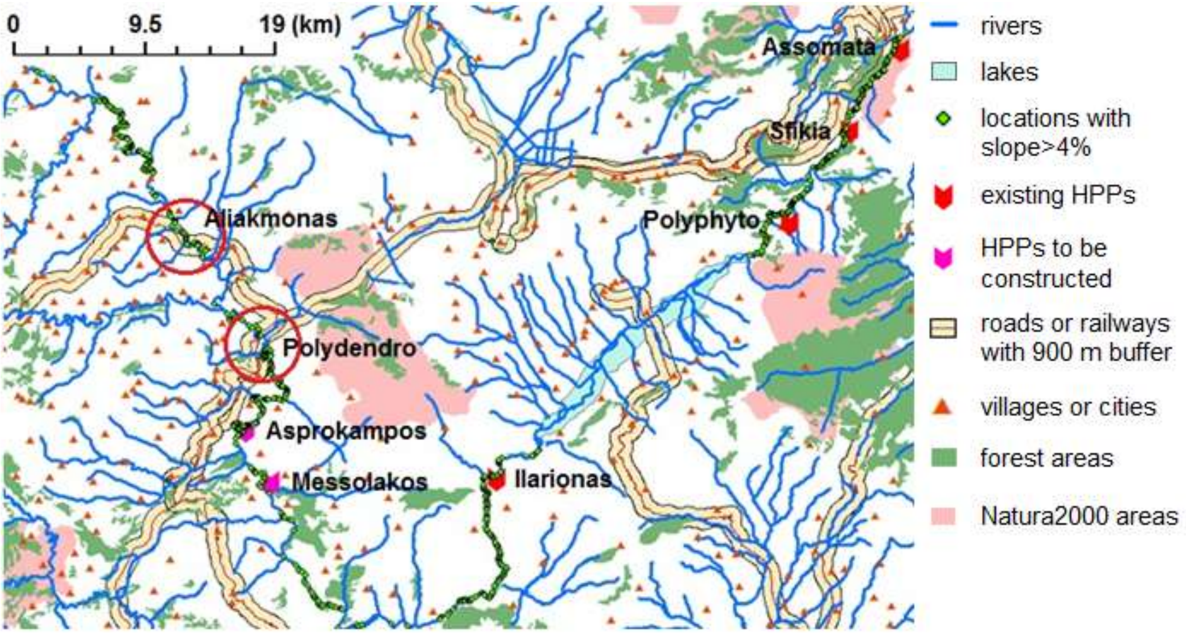

Figure 1: Optimum locations for the construction of the Plant

Figure 1 shows that in the Eastern branch of the Aliakmon river system there are no potential locations for new HPPs, because these have already been exploited by the existing HPPs. Moreover, in the North-Western and Southern parts with no HPPs, there is no road infrastructure. Two small HPPs in Messolakos and Asprokampos are expected to get license for the initialization of construction. Therefore, the only left possible locations are close to the villages Polydendro and Aliakmonas. In this work, we have chosen the first location, for which data were available in Rokas Idroilektriki (2006), who proposed a relatively larger HPP.

3. Preliminary design of the plant

3.1. The characteristics of the multi shaft plant

In the MSPP the power generation system is installed on the riverbed and only a small transformer station is visible in the river banks. The water flows through a trash rack into a box-shaped construction to drive the turbine and is then guided back into the river underneath the dam whereas a part of the flow overtops the construction, as shown in Figure 2b. The trash rack also ensures the sediment transport.

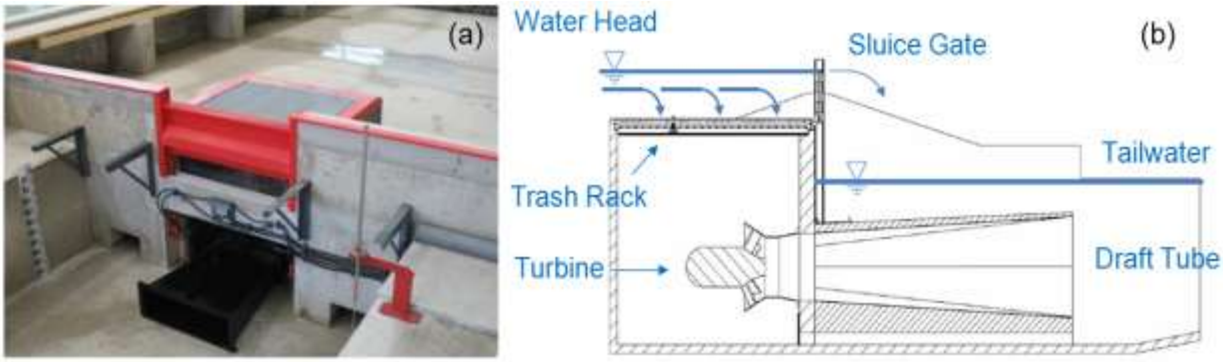

Figure 2: (a)Experimental setup; (b) schematic cross section of the MSPP (Knapp, 2013)

The main advantages of the MSPP include (1) a simple construction and an easy-to-operate system, (2) standardized pre-fabricated modules and thus optimized construction times, (3) low construction costs, (4) low maintenance requirements, (5) minor impact on the landscape and (6) minimal impact on the flow continuity (discharge, morphology and biodiversity of habitats). The MSPP is usually designed for heights and discharges up to 9.0 m and 20 m^3/s, respectively; moreover, several parallel shafts can also be used.

3.2. Design of the plant

1. Main design data of the MSPP; these are shown in Table 1. Due to the underwater position of the equipment, the downstream face of the dam is shaped as a broad-crested spillway, which maintains the complete functionality and structural safety, even when overflow occurs. The available water head can be calculated by determining the difference in water level upstream-downstream of the dam; this can be estimated by using the backwater and tailwater rating curves, which can be approximated by simplified equations, such as the Poleni and Manning formulas, respectively.

2. Characteristics of the turbines and their performance. Three Kaplan turbines were installed, each having a capacity equal to 15.0 m^3/s; their basic characteristics that are shown in Table 1 were determined with the methodology of Giesecke and Mosonyi (2009). This allows the transfer of the characteristics of a prototype (KA75, located in the Laboratory of Hydraulic and Water Resources Engineering in Obernach), to a real size turbine with the same geometrical shape. In Table 2 the performance curve of the turbine is also shown.

The height, width and length of the draft tube outlet were calculated equal to 1.2D=2.39m, 2.93D=5.83 m and 5D=9.94 m, respectively. The following performance characteristics were determined: installed capacity= IC =3.20 MW, full load hours = 4003, 2312 and 1314 for the 3 turbines, partial load hours = 4502, 1480 and 858, and generated output P=10.92 GWh/year. The corresponding main figures of the Rokas Idroilektriki (2006), who used a Q_{des}= 60 m^3/s and H=18.5 m, was IC=9.22 MW and P=26.32 GWh/year; these correspond to the following ratios compared with the MSPP: 1.3 for Q_{des}, 2.1 for H, 2.9 for IC and 2.4 for P.

3. Fish passages. To ensure the downstream and upstream free movement of fish (mainly Barbel and Carp) and their access to areas which are essential to their reproduction, growth, food or shelter, i.e. 'river continuity' (Water Framework Directive, 2000) fish passages were designed in both directions. The characteristics of the proposed upstream fish passage, designed according to Schmutz and Mielach (2013), are shown in Figure 3. A slight inclination of 20° together with a large surface (to reduce velocities; V_{max}<0.5 m/s) of the trash rack guide the fish towards the sluice gate openings over the dam permitting their downstream migration and no other facility is needed.

Table 1: Main design data of the MSPP

Parameter and value	Comments
Q_{des}=Design flow rate = 45 m^3/s	Exceedance frequency=15.4 %, i.e. 56 days per year (Strobl and Zunic, 2006).
Design flood flow rate=1603 m^3/s	Return Period T=100 years
H=Height of the dam = 9.0 m	Selected
Width of crest = 120.0 m	Based on the topography

Table 2: Technical characteristics of the prototype and the real turbine

Turbine	KA75 (Giehl, 2013)	Real	Performance curve	
			Admission Q/Q_{des}	Efficiency (%)
			0.0-0.1	0
Runner diameter D(m)	0.75	1.99	0.1-0.2	0-78
Circular speed (rpm)	333	238	0.2-0.4	78-87
Design discharge (m^3/s)	1.5	15.0	0.4-0.6	87-89
Design water head (m)	2.5	9.0	0.6-0.8	89-90
			0.8-1.0	90-89

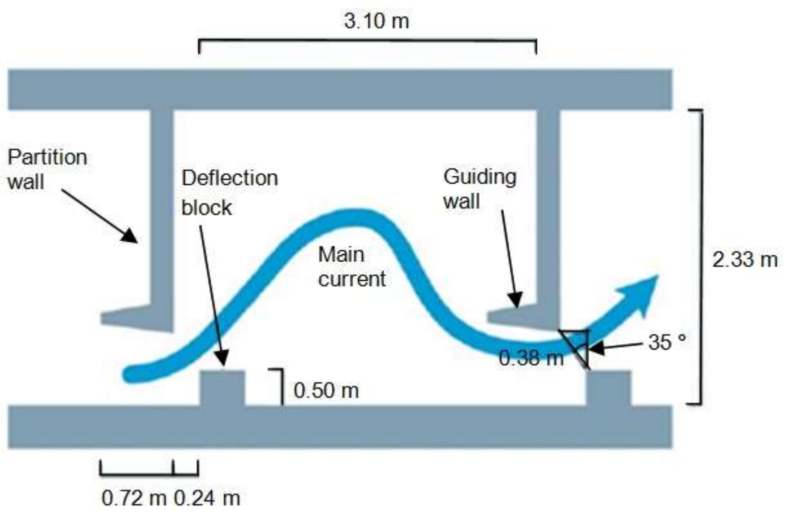

Figure 3: Indicative sketch of the upstream fish passage

3.3. Financial analysis and emission trading

The investment and O&M costs were estimated equal to $6.4x10^6$ €and $175.64x10^3$ €, respectively, based on the empirical figures of 2000 €/kW (Stefanakos, personal communication) and 55€/kW (Bard, 2002), respectively.

Moreover, according to the EU Emission Trading Scheme (EU ETS) and assuming that the Baseline Emission Factor (European average for hydropower) is equal to 0.5 t CO_2/MWh and the price of Certified Emission Reduction (CER) is equal to 0.4 €/ t CO_2, the yearly income of the project from CER was calculated equal to 2184 €/year.

Taking into account the above mentioned costs and that the Feed-in Tariff is equal to 9.0 €/ 100 KWh (Stefanakos, personal communication), the project lifetime is 70 years and the construction period is 2 years, the Internal Rate of Return analysis showed that the project could start being profitable after 8 years for the base case scenario.

4. Conclusions

Energy production by the Multi-Shaft Power Plant is definitely lower than the generated output of a large Hydro Power Plant due to the limited available water head. However, this concept has minor environmental impacts due to its size, but also regarding fish migration and landscape, whereas it is also an economically viable and profitable solution not only due to the low investment and O&M costs but also due to the expected revenues, including the income from Certified Emission Reduction.

ACKNOWLEDGEMENT

The present work was performed in the TUM within the performance of the Study project of the second author; the third author would like to thank TUM, DAAD and NTUA. Moreover, special thanks are to Assistant Professor NTUA N. Mamassis and Rokas Idroilektriki E.P.E. for the provision of data.

REFERENCES

1. Bard J., Development of Market and Cost of Small Hydropower Plants in Germany (up to 5 MW), Institut für Solare Energieversorgungstechnik; Kassel University, 2002.
2. Giehl S. (2013), Machbarkeitsstudieeiner Mehrschachtanlage am Wehr Knottingley unter den besonderen Anforderungen des United Kingdom, Master's Thesis, Technische Universität München, Lehrstuhl für Wasserbau und Wasserwirtschaft, München.
3. Giesecke J. and Mosonyi E., Wasserkraftanlagen. Planung, Bau und Betrieb, Springer, 2009.
4. Knapp W., Hydro Power and Energy Storage, Lecture, Technische Universität München, Lehrstuhl für Wasserbau und Wasserwirtschaft, München, 2013.
5. Rokas Idroilektriki E.P.E., SHPS «Polydendro» Municipality of Heracleota, Prefecture of Grevena, Engineering Report, Athens 2006.
6. Schmutz S. and Mielach C., Measures for ensuring fish migration at transversal structures. Technical paper, International Commission for the Protection of the Danuber River, 2013.
7. Stefanakos J.P. and Rampias E.E. (2009), Present and Future Development of Aliakmon River in Greece, *The International Journal of Hydropower and Dams*, **16(2)**, pp. 88-89.
8. Strobl T. and Zunic F., Wasserbau. Aktuelle Grundlagen – Neue Entwicklungen, Springer, 2006.
9. http://www.heritagecouncil.ie/fileadmin/user_upload/Policy/External_Policy_Docs/Water_Framework_Directive.pdf, (Water Framework Directive, 2000).