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Techno-economic evaluation of small hydro power plants in Greece: a complete sensitivity analysis

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Abstract

Hydropower has by far been the most mature renewable energy resource used for electricity generation in our planet. Recently, the investors' interest was whipped up by the mass development of small hydropower (SHP) stations, as they are the most prosperous for additional hydropower penetration in developed electricity markets. In Greece, the increasing interest for building SHP stations got off the ground since 1994. Ever since, an enormous number of requests keep piling up in the Greek Regulatory Authority of Energy and the Ministry of Development, with the object of creating new SHP stations of total capacity over 600 MW. The present work is concentrated on the systematic investigation of the techno-economic viability of SHP stations. The study is concluded by a sensitivity analysis properly adapted for the local market financial situation, in order to enlighten the decision makers on the expected profitability of the capital to be invested. According to the results obtained, the predicted internal rate of return (IRR) values are greater than 18% for most SHP cases analysed. Finally, as per the sensitivity analysis carried out, the installation capacity factor, the local market electricity price annual escalation rate and the reduced first installation cost are found to be the parameters that mostly affect the viability of similar ventures.

Keywords: Small hydro power stations; Electricity generation; Cost-benefit analysis

1. Introduction

Hydropower has by far been the most mature renewable energy resource used for electricity generation, providing almost $\frac{1}{5}$ of our planet electricity consumption (Paish, 2002). In Greece, several—mostly large—hydroelectric plants (Korbakis and Kaldellis, 2001) are in operation, exceeding 3100 MW of electrical power. Recently, the investors' interest was whipped up by the mass development of small hydro power stations (RAE, 2003), being in accordance with the E.U. target to increase small hydro capacity by 4500 MW (50%) before the year 2010.

In this context, it is important to mention that small hydro power (SHP) plants are the most prosperous way for additional hydro power penetration in European electricity market, considering that most large-scale opportunities have either been already exploited or face serious contradictions by local societies as environmentally unacceptable (Kaldellis, 2002a, b). On the other hand, SHP units usually operate as "run-of-river" systems, thus any dam or barrage used is quite small, not really disturbing the water flow rate. Although to date there is no internationally agreed definition of SHP plant size, the official size in the local electricity generation market is set equal to 10 MW maximum (law 2244/94).

In Greece, an increasing interest for building SHP stations got off the ground since 1994, after the 2244/94 law was voted, permitting private investors to build and operate their own electricity generation stations based on renewable energy sources. In the last 5 years a fair number of SHP plants were established by individuals and local municipalities (Korbakis and Kaldellis, 2001; European Commission, 1999), while at the same time an enormous number of requests keep piling up in the Greek Regulatory Authority of Energy (RAE) and the Ministry of Development, with the objective of creating new SHP station over 600 MW.

The present work is concentrated on the systematic investigation of the techno-economic viability of SHP

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Nomenclature

C	total cost of the installation (€)
CF	capacity factor of the installation (%)
c	electrical energy price (€/kWh)
c_N	power reimbursement per month (€/kW/mo)
d	diameter of the penstock used (m)
E	electricity generation by the proposed SHP station (kWh)
e	electricity price annual escalation rate (%)
e_N	electrical power compensation annual escalation rate (%)
FC	fixed maintenance and operation cost of the SHP station (€)
f	first installation cost coefficient (%)
$f(Q)$	probability density function describing the available water potential (%)
g	gravity acceleration (m/s^2)
g_m	maintenance and operation cost annual inflation rate (%)
H	total head of the hydro turbines used (m)
h	hydrostatic head of the installation (m)
IC_o	SHP station turnkey cost (€)
IRR	internal rate of return of the installation (%)
i	return on investment index (%)
L	length of the penstock used (m)
m	fixed maintenance and operation cost coefficient (%)
N	power output of the SHP station (kW)
N_o	rated power of the hydro-turbines used (kW)
NPV	net present value of the investment
n	service period of the installation (years)
Pr	reduced ex-works price of the installation (€/kW)
p	investment revenues fraction transferred directly to local municipalities (%)
Q	volume rate of the hydro turbine (m^3/s)
Q_b	water bleedings for auxiliary services (m^3/s)
Q_e	minimum flow rate of the river, for ecological protection reasons (m^3/s)
Q_r	river flow rate (m^3/s)
R	total revenues of the investment (€)
t	time (s)
VC	variable maintenance and operation cost of the SHP station (€)
W_o	water annual fees (€)
w	water fees annual escalation rate (%)
Y	residual value of the investment (€)
z	number of turbines used
γ	state subsidization percentage (%)
Δ	technical availability factor of a small hydro power station (%)
δH_f	total hydraulic loss of the system (m)
ζ	local loss coefficient for the water circuit of the SHP station
η	total efficiency of the SHP plant (%)
λ	friction loss coefficient for the water circuit of the SHP station
ξ	specific cost coefficient of civil engineering works (%)
ρ	water density (kg/m^3)
Φ	annual tax on profit (€)
ω	mean power coefficient of the installation (%)

stations in Greece. The proposed analysis takes into account previous works on this field (Liu and Ye, 2003; Georgakelos, 2002; Karlis and Papadopoulos, 2000), along with available information concerning the local hydro potential (Kaldellis and Kavadias, 2000). Accordingly, the impact of the governing techno-economic parameters on the financial behavior of SHP plants is analysed (Kaldellis and Gavras, 2000). This study is concluded by a sensitivity analysis properly adapted for the local market financial situation, in order to enlighten the decision makers on the expected profitability of the capital to be invested.

2. Analytical simulation of small hydropower stations energy production

Hydro-turbines transform the water potential (mainly high pressure) into mechanical shaft power, which is finally converted to electricity (Papantonis, 2001; Fritz, 1984). The electrical power N available of every turbine used is proportional to the product of total pressure head H and volume rate Q of penstock, thus one may write

$$N = \eta \rho g H Q, \tag{1}$$

where η is the total efficiency of the turbine (including the electrical generator), see for example Fig. 1, ρ is the water density and g is the gravity acceleration. Bear in mind that the hydro-turbine head results from the hydrostatic head h of the waterfall and the total hydraulic loss δH_f, both lengthwise and local (λ and ζ are the corresponding loss coefficients) when the water circuit is used for energy production. More precisely,

$$H = h - \delta H_f \tag{2}$$

and

$$\delta H_f = \left(\lambda \frac{L}{d} + \zeta\right) \frac{8Q^2}{g\pi^2 d^4} \tag{3}$$

with L the length and d the diameter of the penstock used.