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On the market of wind with hydro-pumped storage systems in autonomous Greek islands

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ABSTRACT

In autonomous islands, the wind penetration is restricted due to technical reasons related with the safe operation of the electrical systems. The combined use of wind energy with pumped storage (WPS) is considered as a mean to exploit the abundant wind potential, increase the wind installed capacity and substitute conventional peak supply. In this paper, the experience gained from the analysis of WPS in three specific islands is used towards the estimation of the WPS market in autonomous Greek islands. Parameterized diagrams and a methodology towards the pre-dimensioning and initial design of the WPS are proposed and used towards the estimation of the market in autonomous Greek islands. The objective is to make an initial general prefeasibility study of WPS prospects in the autonomous Greek islands. Results show that there is a significant market for WPS in Greece and the development cost of WPS is competitive to the fuel cost of local power stations in autonomous islands.

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1. Introduction

The autonomous electrical systems in Greek islands are based almost entirely on oil. They are characterized by high wind potential and there is a high investor's interest for wind applications. Given the current infrastructure and the technical constraints, the prospects of wind power to decrease both the system's electricity production cost and the dependence on the oil are limited [1,2]. The reason is that wind farms operating in autonomous systems are subject to output power limitations, related with technical constraints of the conventional generating units, namely the minimum loading levels of the thermal units (technical minimum) and a dynamic penetration limit, applied for stability purposes [1–5].

Investors' applications for large scale wind integration, undertaken also the interconnection of the island with the mainland via an underwater cable, face several objections by local populations. A wind with pumped storage (WPS) system – comprised by new wind farms, two reservoirs for the recycling of water, hydro-turbines, pumps and penstocks – is proposed as a mean to increase the wind installed capacity, substitute expensive fuel oil and reduce the required conventional installed capacity in autonomous islands. Last years, WPS has been analysed by the scientific community for various autonomous islands [6–11].

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In the current paper, the experience gained from the systematic application and thorough analysis of specific case studies [12,13] is used for the creation of parameterized diagrams towards the WPS initial design and estimation of the market, in autonomous Greek islands.

The aim is to make an initially design of WPS in all the autonomous Greek islands. The results show that there is a significant market for WPS in autonomous Greek islands. The cost for the development of WPS is comparable to the operational cost of local power stations in autonomous Greek islands.

2. Methodology

The formulation of parameterized diagrams is based on the results of the thorough analysis of three representative Greek case-studies islands [12,13]. All the analysed case studies and the produced diagrams are based on the following design and operational policy of the WPS [8,12]:

- connection of the wind farms with the pumping station through the central grid,
- peak demand supply of the hydro-turbine,
- consideration of the hydro-turbine as a spinning reserve to increase the direct wind power absorbed,
- double penstock and
- complementary pumping using conventional power given the capacity of the committed conventional units.

The target of parameterization and generalization of the results was an initial prospect of all the former works [1,2,8,12,13] and always various attempts of dimensionless parameterization have been tested.

2.1. Capacity of wind farms, reservoir, hydro-turbine

The required wind capacity is inversely proportional to the wind potential (wind capacity factor) and to the efficiency of the WPS (the ratio of hydro-turbine's energy production to the energy used for pumping), and proportional to the annual mean load and the load factor. The annual mean load introduces the amount of the demand and the load factor the seasonal variations of the demand. The same annual mean load could be appeared in a power with relatively low variations (high load factor) and in another with large variations (low load factor). In the latter case, lower wind capacity is required. During the short peak demand period, the WPS could provide the guaranteed power thanks to the reservoir's stored energy, while the rest period of low demand lower wind capacity is adequate.

Respectively, the required volume of the reservoir is inversely proportional to the available hydraulic head and proportional to the average efficiency of the pumping station.

Then, the wind capacity index δ_W and the reservoir's capacity index δ_R are defined:

$$\delta_W = \frac{P_{W,h,R} \cdot CF_{W,th} \cdot n_{PSU}}{\overline{P_L} \cdot LF} \quad (1)$$

$$\delta_R = \frac{V_{RESERVOIR} \cdot H}{3600 \cdot 102 \cdot P_{W,h,R} \cdot CF_{W,th} \cdot n_P} \quad (2)$$

where $P_{W,h,R}$ is the wind installed capacity in the WPS (MW), $CF_{W,th}$ is the wind capacity factor which introduces the wind potential in the island (%), n_{PSU} is the efficiency of the WPS (%), $\overline{P_L}$ is the annual mean load (MW), LF is the load factor of the island (%), $V_{RESERVOIR}$ is the capacity of the reservoir (m^3), H is the hydraulic head (m), n_P is the efficiency of the pumping station (%).

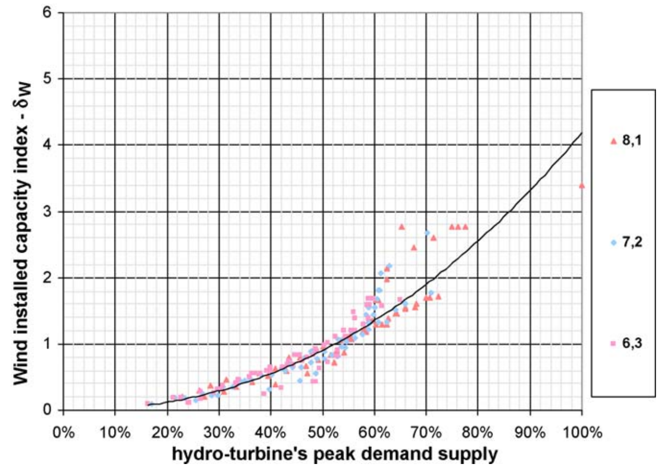

Fig. 1. Diagram for the definition of the WPS wind capacity.

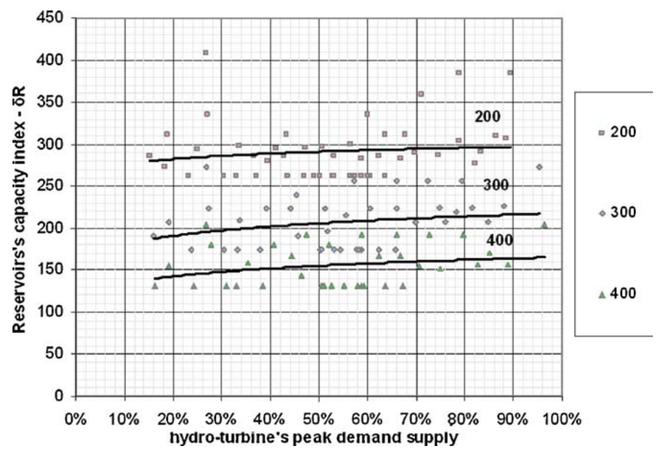

Fig. 2. Diagram for the definition of the WPS reservoir.

The above defined indexes, has been calculated for all the examined case studies and are presented in diagrams (Figs. 1 and 2) as a function of the hydro-turbine's peak demand supply α.

The diagram for the dimensioning of the reservoir is parameterized by the hydraulic head. Then three curves have been adjusted to the available points:

$$\delta_R = \begin{cases} 298.17 \cdot a^{0.0341}, & \gamma\iota\alpha H = 200\,\mathrm{m} \\ 217.74 \cdot a^{0.082}, & \gamma\iota\alpha H = 300\,\mathrm{m} \\ 165.54 \cdot a^{0.0933}, & \gamma\iota\alpha H = 400\,\mathrm{m} \end{cases} \quad (3)$$

$$\delta_W = 4.1889 \cdot a^{2.2133} \quad (4)$$

These diagrams (Figs. 1 and 2) or the formulas (3) and (4) can be used for the initial design and dimensioning of the WPS, given the basic data of the autonomous power system (annual peak demand, mean annual load of the system and the load factor).

To start with the setout of the dimensioning, one of the following parameters should be initially defined:

- the desirable hydro-turbines peak demand supply,
- the available reservoirs capacity,
- or the wind capacity to be installed.

2.2. Energy contribution of the WPS

Wind potential and hydraulic head are site-dependent features, which strongly affects the attractiveness and the profitability of