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Optimum sizing of stand-alone wind-photovoltaic hybrid systems for representative wind and solar potential cases of the Greek territory

J.K. Kaldellis *, D. Zafirakis

Lab of Soft Energy Applications & Environmental Protection, Mechanical Engineering Department, TEI Piraeus, Egaleo, Greece

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ABSTRACT

Wind and solar driven stand-alone systems can under certain conditions comprise attractive electrification solutions for numerous isolated consumers worldwide. However, due to their requirement for considerable energy storage capacity, diesel generator sets are normally used instead. To minimize oil consumption, the idea of creating a combined wind — photovoltaic (PV) based hybrid system with the use of an appropriate energy storage device is currently investigated. In this context, the main target of the specific work is to estimate the appropriate size of a similar system, so as to meet the energy demand of typical remote consumers under the criterion of minimum first installation cost. Representative case studies of the Greek territory with different quality of wind and solar potential are currently investigated, with the results obtained designating the advantages of the proposed solution, especially for locations of low wind potential. Furthermore, according to the results, the critical role of the local wind potential on the optimum size of such configurations is reflected, while variation of the local solar potential in the Greek territory seems to only slightly influence the minimum first installation cost solutions.

1. Introduction

There are several research works (Fragaki and Markvart, 2008; Kaldellis, 2001; Kaldellis et al., 2003; Weisser, 2004) investigating the performance of stand-alone systems, destined to meet the electrification requirements of isolated consumers worldwide on the basis of either wind power or solar energy. According to the conclusions of these studies, to satisfy electricity demand at all times, i.e., during calm spells and night-time as well, considerable energy storage capacity is required so as to store any energy surplus during high wind speed and high solar radiation periods. However, the direct result of this strategy is excessive energy storage capacity that also leads to increased first installation and operation costs. At the same time, in several areas of our planet wind speed and solar radiation present supplementary (Kaldellis et al., 1999) availability, hence the combined exploitation of the available wind and solar potential may reduce considerably the energy storage capacity requirements of stand-alone systems, taking into account that although the solar energy distribution is basically periodic, wind speed may present stochastic patterns.

To this end, there are several studies examining performance of similar systems. More precisely, Notton et al. (2011) studied the performance of hybrid wind-photovoltaic (PV) systems for the area of Corsica, considering different wind potential areas and designating the important factor of complementarity between wind and solar potential. Next, Ekren and Ekren (2009), investigated the performance of a similar configuration under two distinct load demand profiles, using detailed wind and solar measurements from a meteorological station installed in Izmir. Accordingly, Diaf et al. (2008) also studied the techno-economic performance of a wind-PV system for the area of Corsica, examining three different sites of distinct characteristics on the basis of loss of power supply probability. Moreover, Khatib et al. (2012) studied the possibility of applying hybrid wind-PV configurations in the area of Kuala Terengganu, Malaysia, while finally, Nandi and Ghosh (2010) investigated the prospects of such systems for remote areas of Bangladesh, in comparison to the alternative of electricity grid extension.

At the same time, investigation of the hybrid wind-PV solution is not yet undertaken for the remote communities of the Greek territory. In this regard, an effort is undertaken in the present work so as to examine the prospects of applying such configurations in Greece, complementing previous works of the authors concerning applicability of wind only- and PV only-based stand alone systems (Kaldellis, 2001; Kaldellis et al., 2003).

In this context, at the east side of the Greek mainland, where the area of the Aegean Archipelago is located, there are several hundreds of scattered islands. In the specific region there is a considerable number of isolated consumers (Kaldellis, 2001;

* Corresponding author. Tel.: +30 210 5381237; fax: +30 210 5381348.
E-mail address: jkald@teipir.gr (J.K. Kaldellis).
URL: http://www.sealab.gr (J.K. Kaldellis).

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Kaldellis et al., 2003) that have no access to a constant and reliable electricity source. As a result, the respective consumers are forced to meet their needs using small diesel-electrical generators that consume considerable amounts of expensive oil imports. At the same time, these islands are favoured with an abundant solar energy potential (Flocas, 1980) for the entire year, while their majority also possesses high-quality wind potential (Fyrippis et al., 2010; Kaldellis, 2008; Kanellopoulos, 1992), e.g., Fig. 1. On top of this, for many of the Aegean Archipelago areas, wind and solar potential present supplementary availability, see for example Fig. 2(a) and (b). In an attempt to minimize oil consumption and improve the life-quality of isolated consumers, the idea of creating a combined wind-PV hybrid system (Arribas et al., 2010; Dehghan et al., 2009; Diaf et al., 2008; Nema et al., 2009; Notton et al., 2011; Zhou et al., 2010) with the use of an appropriate energy storage device (Ibrahim et al., 2008; Kaldellis et al., 2009) is currently investigated for representative case studies.

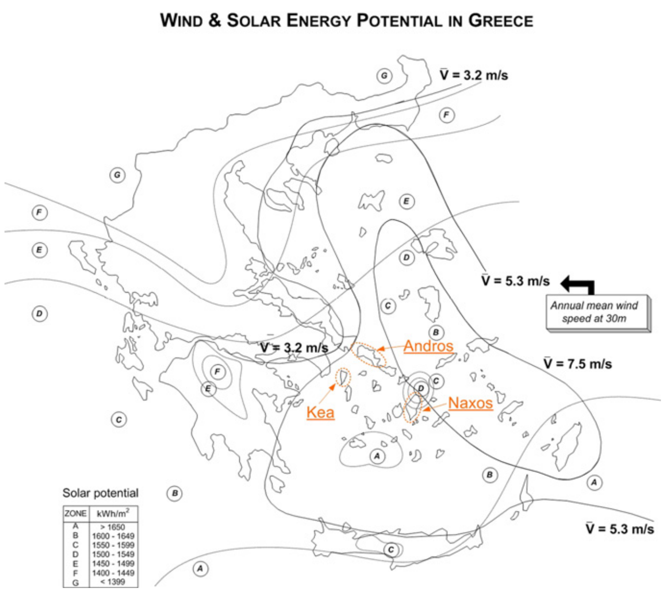

Fig. 1. Variation of the wind and solar potential in Greece.

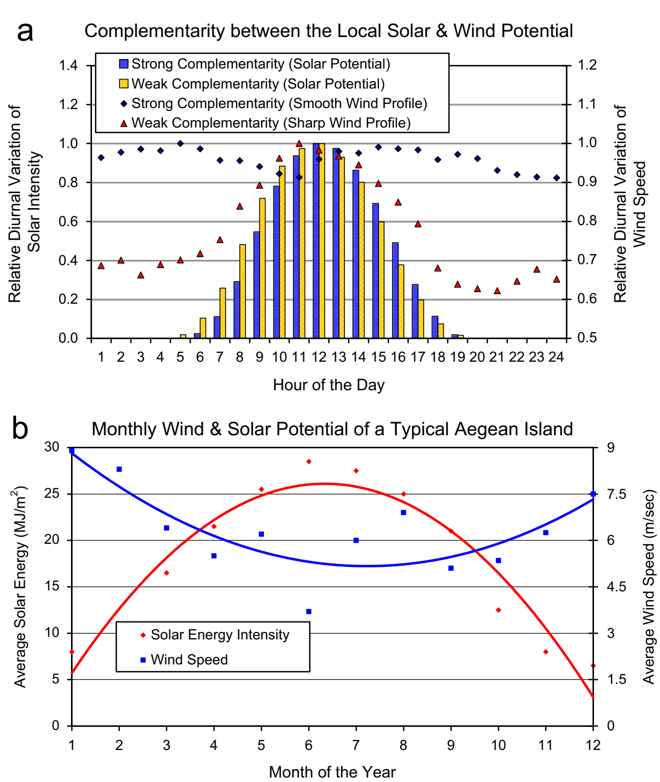

Fig. 2. (a) Comparison of the mean diurnal variation of wind and solar potential between two representative Aegean Sea areas suggesting a strong and a weak supplementary availability case. (b) Monthly variation of the wind and the solar potential in a typical Aegean Sea area.

Among the main targets of the specific work is the estimation of the optimum size of a typical stand-alone wind-PV power system, under the restriction of minimum first installation cost. For this purpose, a simulation algorithm is developed so as to incorporate all problem inputs and provide the appropriate system size for several energy autonomous hybrid configurations. The resulting energy autonomous configurations are accordingly evaluated using the criterion of minimum first installation cost, while emphasis is currently given on the impact of the local wind and solar potential.

2. Position of the problem

In order to determine the dimensions of a wind-PV stand-alone system that is able to meet the electricity demand of a typical remote consumer the following problem inputs are necessary:

i. *The electricity demand of the consumer*: Three representative weekly electricity consumption profiles are selected (Kaldellis, 2001; Kaldellis et al., 2003), on an hourly basis, being also dependent on the year period analyzed (winter, summer, other). The data used (Fig. 3) are based on information provided by the Greek National Statistical Agency, while any other electricity consumption profile (Lazou and Papatsoris, 2000) may equally well be used for the present analysis. In particular, the annual peak load "N_{peak}" of the remote consumer does not exceed 3.5 kW on the basis of an appropriate demand side management strategy, while the respective annual energy consumption "E_y" reaches approximately 4.75 MW h.

ii. *The wind potential of the area*: In the specific case detailed wind speed measurements of at least one year should be used (Public Power Corporation (PPC), 1986), although the proposed analysis may handle time periods of much greater time length; any case given, a three-year period is assumed to be sufficient for a location to be evaluated.

iii. *The solar potential of the area*: For the estimation of solar radiation values in the area under investigation, one may use either theoretical models properly adapted (Kaldellis and Kavadias, 2000) in accordance to the available global measurements or detailed measurements (Public Power Corporation (PPC), 1986) pertaining to the global solar potential on an hourly basis, at least.

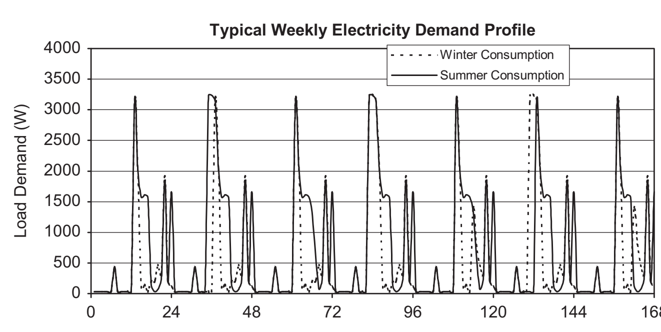

Fig. 3. Typical electricity demand profile of the remote consumer under investigation.