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Cost benefit analysis of a photovoltaic-energy storage electrification solution for remote islands

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ABSTRACT

A large number of various sized islands are spread throughout the south-east Mediterranean Sea. Most of these small islands face serious infrastructure problems, like the insufficient power supply and the low quality of electricity available at very high production cost. In an attempt to improve the life quality of all these isolated communities, an investigation concerning the financial viability of an integrated electrification solution based on one or more photovoltaic generators and an appropriate energy storage system is described. The main target of a similar solution is to maximize the contribution of the photovoltaic generator and minimize the life-cycle electricity generation cost of the remote island networks investigated. In addition, special emphasis is given in order to select the most cost-efficient energy storage configuration available. According to the results obtained for high and medium–high solar potential regions, the proposed configuration is found to be more cost-effective than the existing thermal power stations. Several side benefits like the improved electrical network reliability and the minimization of the environmental and macroeconomic impacts resulting from the replacement of the imported oil should also be considered.

1. Introduction

The Greek territory includes a large number of islands of various sizes, spread throughout the Aegean and Ionian Archipelagos, Fig. 1. Although most large and medium-size islands present an acceptable status of life, this is not the case for the small and very small ones. In this context, due to the severe infrastructure problems and the imported oil-based electricity generation, the corresponding production cost is extremely high (Fig. 2). Additionally, the considerable increase of population during the summer season, owed to the visiting tourists, often leads to extensive electrical black outs due to the insufficient power supply [1]. On the other hand, the specific areas are favoured by a considerable RES potential [2], both wind and solar, that should not be neglected.

To confront the electrification problems and ameliorate the life quality of the specific areas [3–5], the adoption of alternative electricity generation schemes, such as RES based energy storage configurations [6–10], should be investigated. In this context, the aim of the present study is the financial evaluation of combining photovoltaic (PV) plants with energy storage systems (ESS) for the electrification of small, remote island electrical grids. Several small and tiny Greek islands with a population of less than 2000 and 500 habitants [11], respectively, comprise the target group of the specific research. Their hourly electricity consumption being less than 1 MWh and their peak load demand being inferior to 3 MW (see also Fig. 2) justify the decision to test the PV-ESS solution. Besides, one cannot neglect the support expected from the local habitants in favour of the RES based solution proposed [12,13].

Further, although the first installation cost of a combined PV-ESS configuration is relatively higher than the corresponding of an equivalent thermal power station, the high solar potential of the area and the extremely high production cost of the local APS already mentioned allow for the comparison of the two electricity generation schemes. In this context, by applying an appropriate sizing methodology, various representative PV-ESS configurations are dimensioned in order to minimize the operation of the local thermal power station (APS). Finally, since the optimum sizing of an ESS [14–16] ensures higher system reliability and potential financial gains [17], by using different energy storage technologies [18,19] the designation of minimum life-cycle cost solutions [20,21] may be configured.

2. Description of the problem – proposed solution

The problem to be solved concerns the definition of the most cost-effective PV-ESS configuration, able to meet the electricity requirements of the existing small, remote islands. For this purpose one needs:

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Solar potential	
ZONE	kWh/m^2
A	>1650
B	1600 – 1649
C	1550 – 1599
D	1500 – 1549
E	1450 – 1499
F	1400 – 1449
G	<1399

Fig. 1. Aegean–Ionian islands investigated and solar potential distribution of the Greek territory [2].

2.1. The electrical load demand time variation

Note that for almost all small islands under investigation there is a serious seasonal electricity consumption variation, Fig. 3. In fact, during the summer season, electricity consumption is more than twice the corresponding spring one. In addition, there is also an important daily load demand variation, usually presenting two distinct maxima, one around noon "N_{p1}" and the other (which is normally the biggest one) during late evening "N_{p2}" (Fig. 4). Due to the specific character of the PV production one should separate the daily electricity consumption in two separate periods, i.e. one during sunlight "E_{t1}" and the other during the rest of the day "E_{t2}" [22]. According to the analysis of the available data [1,22], "E_{t1}" represents approximately 30% of the total annual consumption "E_{tot}", taking values between 15% and 45% on a daily basis. Note also that:

$$E_{tot} = E_{t1} + E_{t2} \tag{1}$$

and

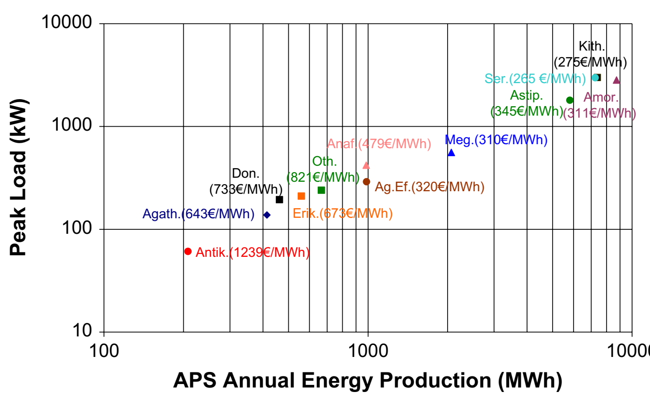

Fig. 2. Small Greek islands' peak load demand, APS annual energy production and electricity generation cost (€/MWh) [1].

$$N_p = \max\{N_{p1}; N_{p2}\} \tag{2}$$

where "N_p" is the peak load demand of the electrical network under investigation.

2.2. The solar irradiance levels of the area

At this point it is worthwhile mentioning that the entire Greek island territory is characterized by high or medium–high solar irradiance. In fact, the annual solar energy at horizontal plane [23] varies between 1500 kWh/m^2 and 1700 kWh/m^2 (Fig. 1). In this context, the exploitation of the available solar potential may significantly contribute to the fulfillment of the local societies energy demand, at minimum environmental and macroeconomic cost [24,25]. As a result, the inhibition of the local societies' economic growth may be encountered [26].

2.3. The appropriate energy storage techniques available

An energy storage system (ESS) is utilized in order to store energy during high electricity production periods and return it to the consumption at low solar irradiance periods or at nights. This system is characterized by the energy storage capacity "E_{ss}" and the nominal input "N_{in}" and output power "N_{ss}" of the entire energy storage subsystem. One should also take into account the desired hours of energy autonomy "d_o" of the installation, the maximum permitted depth of discharge "DOD_L", the energy transformation efficiency of the ESS "η_{ss}", the power efficiency "η_p", as well as its two initial cost components, "c_e" and "c_p". In fact, "c_e" (€/kWh) is related to the storage capacity and type of the system, while the second "c_p" (€/kW) is referring to the nominal power and type of the storage system. Note that the contribution of the ESS to the operation of the proposed integrated solution is expressed via the energy contribution parameter "ε", defined as