Applied Energy 173 (2016) 238–254

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Investigating the techno-economic perspectives of high wind energy production in remote vs interconnected island networks

M. Kapsali [a,*], J.K. Kaldellis [b], J.S. Anagnostopoulos [a]

[a] National Technical University of Athens, Greece
[b] Lab of Soft Energy Applications & Environmental Protection, TEI of Piraeus, Greece

HIGHLIGHTS

- The techno-economic viability of high wind energy share at local level is examined.
- Two scenarios for covering future electricity needs of Lesbos island are investigated.
- Autonomous development is compared to the scenario of interconnection with mainland.
- The Levelized Cost of Energy is calculated for the time-period 2020–2045.
- Based on the results island's interconnection presents considerable economic interest.

ARTICLE INFO

Article history:
Received 28 October 2015
Received in revised form 10 March 2016
Accepted 6 April 2016
Available online 16 April 2016

Keywords:
Levelized Cost of Energy
Mainland
Submarine interconnection
Thermal Power Plants
Island electricity grid
Wind energy rejection

ABSTRACT

The electrification of the non-interconnected Greek islands is mainly based on Autonomous Power Stations (APS), which consume conventional fossil fuels at high energy production cost, while in most cases the contribution of Renewable Energy Sources (RES) (mainly wind) accounts for a small percentage of total electricity generation in these regions. On the basis of comparative analysis of alternative "development scenarios" for electricity generation, the main objective of the present study is to investigate the techno-economic viability of high Wind Energy (WE) share at local (island) level, in accordance to the energy and climate change commitments undertaken by the country, having as central feature large-scale penetration of RES. In this context, the possibilities of increasing WE contribution are examined through the use of an integrated theoretical model developed from first principles, assuming two main possible scenarios for covering future electrification needs of a medium-sized Greek island, i.e. Lesbos. The first scenario (S1) is based on autonomous development of the island keep using as main source for electricity generation oil products. The second scenario (S2) involves the interconnection (IC) of the island with the mainland grid for satisfying part of electricity demand by establishing two alternative solutions, i.e. S2a: without the contribution of local Thermal Power Plant (TPP) and S2b: TPP are maintained to ensure electrification of the island. Subsequently, the economic feasibility of the above options is investigated in terms of their Levelized Cost of Energy (LCOE), calculated for the time-period 2020–2045, including also a sensitivity analysis on worst/reference/best Cases for future electricity demand and production cost. According to the obtained results, IC of Lesbos island with the mainland grid presents considerable economic interest in comparison to autonomous development, with WE having a dominant and an essential role towards that direction.

1. Introduction

Within the framework of Greece's alignment with EU's policies on energy and climate change in 2020 and 2050, the country has undersigned commitments whose main feature is the large-scale penetration of Renewable Energy Sources (RES) and the protection of the environment. A prerequisite for achieving this goal is the complete restructuring of the domestic power sector combined with significant investments in distribution and transmission networks [1,2]. In this context, the main focus of many studies [3–7] in the last few years is paid on possible interconnection (IC) of Aegean Sea islands with the mainland grid for enhancing security of supply into these isolated regions and reducing the polluting oil-fired

* Corresponding author.
E-mail address: marinakaps@hotmail.com (M. Kapsali).

http://dx.doi.org/10.1016/j.apenergy.2016.04.021
0306-2619/

power generation [8–11]. As a result, some projects, such as the IC of some major Cycladic islands with Attica region [10] (Fig. 1), have already entered a mature phase and they will be introduced into operation in the coming years. On the other hand, some other projects, such as the IC of Crete (i.e. the biggest of Greek islands) or other Aegean Sea islands with the mainland system, have been blocked or planned on a more long-term basis as the budget required for their development is quite challenging under the current economic conditions of the country.

The energy production in the non-interconnected Greek islands is mainly based on oil-fired power generation which suggests high electricity generation costs that may even exceed 200 €/MW h. At the same time, Greek Public Power Corporation (PPC) (i.e. the exclusive supplier of the energy deriving from fossil fuels combustion in the islands) faces electrification problems mainly due to power shortage, weak transmission electricity networks and outdated thermal power units. Taking into account the high and almost unexploited wind potential that most of Greek islands possess, Wind Energy (WE) could be an economically attractive solution in order to face electrification problems [12]; however, due to the stochastic availability of wind and the remarkable fluctuations of daily and seasonal electrical load demand, strict WE penetration limits are imposed [13–15]. The result of these penetration limits is that remarkable WE amounts should be rejected on an annual basis, leading to severe financial losses of the Wind Farm (WF) owners. As a consequence, every new attempt to increase WE contribution into remote island networks and establish wind power as a trustworthy electricity generation solution will remain without success unless radical changes take place [16]. To this end, installation of energy storage applications [17–21] or IC of these remote regions with larger power systems [22,23] such as mainland grids, can be seen as options of particular interest.

In this regard, the main objective of the present study is to investigate the techno-economic viability of high WE use at local (island) level, on the basis of two alternative scenarios for covering future electrification needs (during a 25-year period, from 2020 to 2045) of the third in size Greek island, i.e. Lesbos. The first scenario (S1), which is examined for comparison purposes, assumes that the island will keep using, as main source for electricity generation, oil products. The second scenario (S2) involves the IC of the island with the mainland grid for satisfying part of electricity demand while remarkable WE penetration is also achieved. The economic feasibility of the above options is examined in terms of a preliminary study by assessing their Levelized Cost of Energy (LCOE), while also including a sensitivity analysis on worst/reference/best (pessimistic/baseline/optimistic) Case scenarios. At this point it should be mentioned that given the fact that many efforts made in the past on the IC of Greek islands with the mainland system did not succeed [3,7], the novelty of the present paper lies on the investigation – through a parametric study which varies in both WF and submarine IC capacities – of the reinforcing role that the large-scale WE development can play in the techno-economic viability of these projects. On top of that, the present study focuses on a single-project owner perspective assuming that the main scope is to increase RES penetration in both local and national level. This approach might be of particular interest to the national planning authorities in their attempt to design a cost-effective system which has as a main feature the large-scale penetration of RES. However, it is noted that this study investigates the system performance only from the energy-economic point of view based on first principles, and does not include any dynamic stability constraints or contingency analyses.

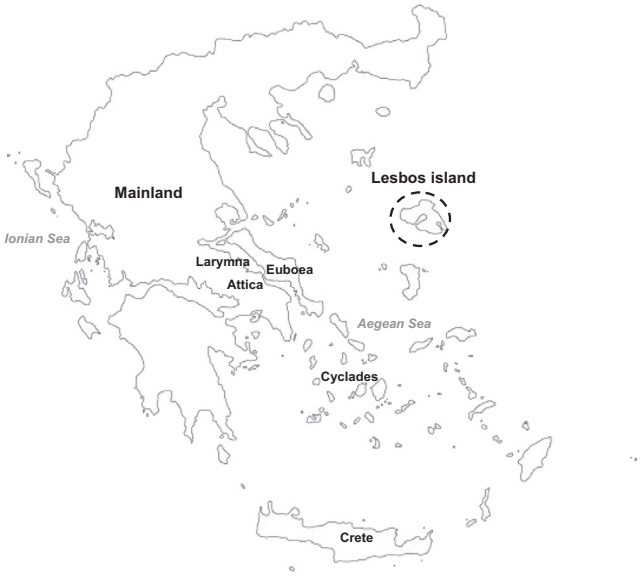

Fig. 1. A map of Greece.

2. Case study presentation

2.1. Description of the system

The island used as a study case in this paper is Lesbos, which is located in the North-Eastern part of the Aegean Sea (Fig. 1) and it is the third in size island of Greece with an area of 1630 km^2. It represents a typical case of a medium-sized Greek island which faces significant electricity generation problems related to several blackouts especially during summer months. The system is primarily supplied by an Autonomous Power Station (APS), comprising several oil-fired generators, which consume on annual basis significant oil-fuel quantities (approx. 60,000 t per year).

The WE potential of the island is quite significant, with the annual mean wind speed being approx. 8 m/s (at 10 m height) (Fig. 2). In fact, three major WFs, of total rated power 13.7 MW (two state-owned and one privately-owned), located to the western part, contribute to the electrification of the island. According to official data concerning the real load demand time-series, as well as the corresponding wind power absorption from the local grid [24] it appears that the contribution of the existing WE applications to the annual energy supply is currently quite small, i.e. well below 15% of the annual demand.

As for solar power, with an average annual radiation per square meter being between 1700 and 1800 kW h/m^2 the total installed photovoltaic (PV) capacity has reached 8.8 MW [25,26]. PVs annual energy production is about 1550 MW h$_e$ per installed MW on an inclined plane (30°) with the Capacity Factor (CF_{PV}) being approx. 18%. Total PVs energy production is estimated ~14,000 MW h$_e$ per year [25].

2.2. The estimated load growth

The energy consumption and the peak load demand of Lesbos island have increased significantly over the past 30-years with an average annual growth rate of ~4.5%. Nevertheless, this high growth rate has been gradually decreased during recent years mainly due to the financial crisis and the unfavourable economic conditions of the country. Specifically, over the past 10-years, the energy consumption and the peak load demand increased with an average growth rate of the order of 1.2% and 1.7%, respectively. Currently, the annual energy consumption of the island exceeds 300 GW h$_e$, while peak load demand is about 70 MW.