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Presentation of a stochastic model estimating the wind energy contribution in remote island electrical networks

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ABSTRACT

The electrification in remote islands whose electricity distribution network is not connected to the mainland's grid is mostly based on Autonomous Power Stations (APSs) that are usually characterized by a considerably high electricity production cost, while at the same time the contribution of Renewable Energy Sources (RES) in these regions accounts for less than 10% of the total electricity generation. This actually results from the fact that despite the excellent wind potential of most of these islands, the wind energy contribution is significantly restricted from limits imposed to protect the remote electrical grids from possible instability problems, due to the stochastic wind speed behavior and the variable electricity consumption. On the basis of probability distribution of the load demand of a representative Greek island and the corresponding data related to the available wind potential, the present study estimates the maximum – acceptable by the local grid – wind energy contribution. For that reason, an integrated computational algorithm has been developed from first principles, based on a stochastic analysis. According to the results obtained, it becomes evident that with the current wind turbine technology, wind energy cannot play a key role in coping with the electrification problems encountered in many Greek island regions, excluding however the case of introducing bulk energy storage systems that may provide considerable recovery of the remarkable wind energy rejections expected.

1. Introduction

During the last years, EU has set ambitious targets towards achieving compliance with the Kyoto Protocol commitments, aiming at a 20% share of Renewable Energy Sources (RES) in the final energy consumption by 2020 [1]. According to the Greek Law 3851/2010, the target set for Greece aims to increase the contribution of RES to the gross energy consumption up to 20% by 2020, while the corresponding percentage for the electricity consumed has been set equal to 40% [2]. Among the available RES technologies, wind power is expected to contribute the largest part since Greece is favoured with excellent wind potential which in many cases is determined by mean annual wind speeds that exceed 8 m/s.

Currently, in Greece, the main electricity production originates from lignite and imported fossil fuels such as oil and natural gas, while the contribution of RES in the national energy balance still remains small (i.e. almost 6% of the gross total energy consumption). Meanwhile, the installed capacity of wind farms in the country has recently exceeded 1 GW, from which approximately 250 MW are used to supply the non-interconnected Greek islands. In fact, the energy production in the non-interconnected islands is currently based mostly on Autonomous Power Stations (APSs) which consume imported amounts of fuel oil (mazut, diesel), while the contribution of RES accounts for only 9% of the total electricity generation in these regions. Specifically, in 2008, the total electricity production in the islands was approximately 6250 GW h_e from which just 580 GW h_e derived from renewables [3].

One of the main reasons which decelerates the development of wind power installations is the stochastic behavior of wind which has led to strict wind energy penetration limits [4] imposed to protect the electrical grids from possible instability problems [5,6]. In fact, the smaller the electrical network is, the more imperative the problem of wind energy management becomes (e.g. island regions even with the size of Crete, i.e. approx. 8300 km^2). In most cases the autonomous electrical networks cannot continuously absorb the variable power output of local wind farms, especially during the low consumption periods of the year in order to protect the existing thermal power units from operating below their technical minima [7].

A major factor which affects the wind power penetration is the intense electrical load demand fluctuations encountered on daily and annual basis in the islands. The summer peak load demand may be up to four-times the minimum winter load demand (see Fig. 1), while even during the same day one may observe significant load demand variation (Fig. 2).

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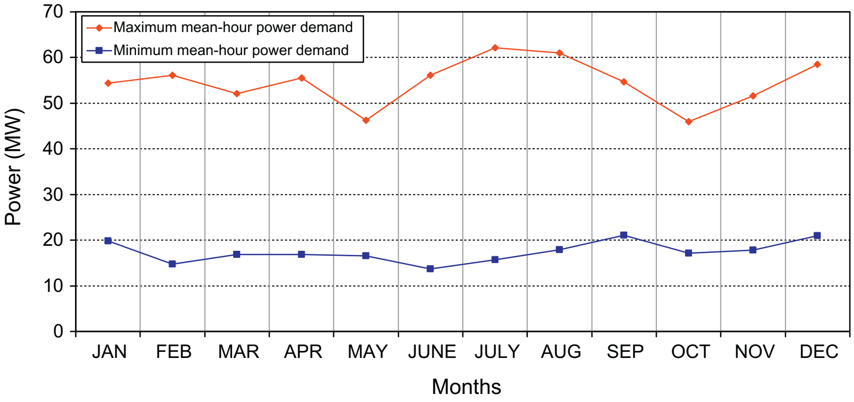

Fig. 1. Maximum and minimum electric power demand of a selected Greek island (Lesbos) [8].

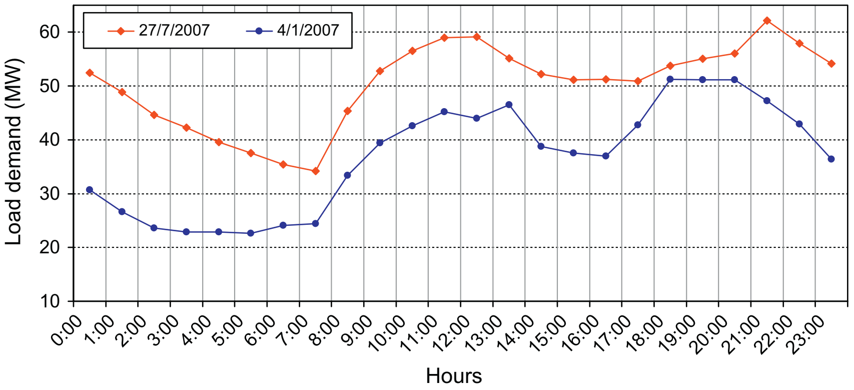

Fig. 2. Daily load demand fluctuations in a selected Greek island (Lesbos) [8].

Practically, the thermal engines must always have the ability to cover in a short time period a sudden loss of the wind energy production so to avoid a partial or a total black-out [9]. Furthermore, under the current Greek legislation frame, the local Transmission System Operator (TSO) may reject wind energy amounts in case that they cannot be absorbed, e.g. during the hours of low electricity demand (i.e. nights) even when there is increased wind energy production (i.e. periods of high wind speed). Consequently, it is difficult to achieve wind energy contribution that is higher than 15% in autonomous electrical networks [10], unless economically viable energy storage techniques (e.g. pumped hydro storage) that are able to exploit the excess wind energy amounts produced by local wind farms [11–14] are implemented. In this context, if the exploitation of the rejected wind energy amounts is the objective, then, the sizing procedure of a hybrid system which incorporates wind energy storage requires the estimation of the expected energy curtailments produced by the involved wind farms (new and existing) [15].

The present study is focused on calculating the maximum wind energy yield, which may be acceptable by an autonomous electrical network, on the basis of probability distribution of the local grid load demand and the corresponding data related to the available wind potential. Subsequently, the expected wind energy curtailments are also estimated. For this purpose, a user-friendly computational algorithm has been developed from first principles, based on stochastic analysis. The developed numerical code is accordingly applied to a representative Aegean Sea island, i.e. Lesbos, in order to demonstrate its applicability for other similar island cases as well. Finally, the calculated results are analyzed in detail in view of the operational regions of contemporary commercial wind turbines.

2. Position of the problem

The problem to be solved in the present study concerns the development of an integrated computational algorithm that enables the estimation of the wind energy yield that may be absorbed by an autonomous electrical network and therefore the determination of the expected wind energy curtailments for various wind farms' sizes on the basis of stochastic analysis.

For estimating the above, one first needs the electrical load demand profile of the island under investigation. In this context, one may obtain either long-term load demand time-series data or the corresponding probability density distribution "f_L", with the probability "P_L" for the load demand to vary between two specific values "N_{L1}" and "N_{L2}" given as:

$$P_L(N_{L1} \leqslant N_L \leqslant N_{L2}) = \int_{N_{L1}}^{N_{L2}} f_L(N_L) \cdot dN_L \qquad (1)$$

Subsequently, by using Eqs. (2)–(4) [9,10] one may estimate the maximum wind power penetration "N_w^*" into the island's grid, on the basis of the technical minimum "$N_{d_{\min}}$" (i.e. minimum permitted power output) of each thermal engine which operates in the APS. The technical minimum of each engine is expressed via an appropriate factor "k_i" and the rated (or maximum) output power "$N_{d_i}^*$" of the unit under investigation. On top of this, the annual maintenance plan of the system, affecting the number ($i_{\max}$) of the "on duty" engines during the year, should also be considered [15]. Thus,

$$\mathit{If}\ N_L(t) \leqslant N_{d_{\min}}(t) = \sum_{i=1}^{i=i_{\max}} k_i \cdot N_{d_i}^* \rightarrow N_w^*(t) = 0 \qquad (2)$$