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Component sizing for an autonomous wind-driven desalination plant

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Abstract

Objective of this paper is to provide insight in the component selection criteria of an autonomous wind-driven desalination plant. For this purpose, a suitable logistic model of such a system is developed, which simulates its steady-state operation, taking into account the power and energy equilibrium in the system. The simulation of the system operation is performed employing two alternative control strategies and a variety of different configurations with respect to the size of its main components (wind turbine, desalination plant and batteries). For each case, the annual water production is calculated and an economic assessment is performed to estimate the expected water production cost, which is the ultimate measure of the feasibility of the stand-alone system. Other important factors, such as the desalination unit start/stop operations are also calculated. Based on the simulation results, conclusions are drawn regarding the optimal sizing of the system components and its recommended operating strategy.

Keywords: Desalination; Reverse osmosis; Autonomous systems; Wind power; Lead-acid batteries; Logistic modelling

1. Introduction

In many isolated regions with good wind energy potential, there exists a significant growth of fresh water demand, which often exceeds the sustainable local water resources. In such cases, wind-driven stand-alone desalination units provide an environment friendly,

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cost-effective and energy efficient method for the production of potable water. In fact, wind energy is the most attractive renewable energy source for such applications, being a technologically mature choice with low cost and good reliability. Regarding the water desalination technologies, reverse osmosis (RO) is widely used in the last years mainly due to its low energy requirements compared to other competitive techniques.

The fundamental consideration in the development of a stand-alone system for water desalination is the sizing of its components, in order to meet a specified water production level, at a minimum investment and operating cost. There is a significant number of studies which have dealt with this issue [1–7]. No single answer exists for the proper selection of the components and each system is inevitably dealt with on a case-specific basis. The limited availability of small wind turbines (WTs) in the market has been a further constraint until today. This constraint is gradually relaxed as more machines become available in the range 1–50 kW, a trend driven among other things by the increase in the demand for small-scale autonomous systems [8].

To provide some insight in the component selection issue, a logistic model has been developed and used to simulate the operation of a small stand-alone system, comprising a WT, batteries and a desalination unit, with power ratings in the range 10–50 kW. The modelling is based on the energy and power equilibrium and is therefore suitable for the long-term simulation of the steady-state operation of the system (typically 1 year, with a 10-min time step). Main input to the model is the wind speed time series. Most significant outputs are the annual water production, the number of starts and stops of the desalination unit and the energy production/consumption of various components.

Using the developed logistic model, first the effect of the operating strategy is investigated, by comparing two alternative control concepts. Then, an extensive investigation is presented, considering different sizes of desalination plants (DPs), WTs and battery capacities, in order to assess quantitatively the effect of their relative size on the expected water yield and quality of operation. In all cases, the ultimate economic evaluation criterion is the specific water production cost. Based on the simulation results, important conclusions are drawn regarding the implications from the selection of the system components.

2. Description of the autonomous system

In Fig. 1, the basic structure of the autonomous system is shown, including the WT, the DP, the battery bank, the dump load and other secondary electrical loads, all connected to a common AC bus. In this paper, three WT types were considered, all commercially available at the time of the study, rated 15, 20 and 50 kW. Their power curves are shown in Fig. 2. WTs of such a size are either constant speed machines, equipped with induction generators directly coupled to the AC bus, or variable speed units, usually comprising a permanent magnet synchronous generator, interfaced to the system bus via an AC/DC/AC converter. The WT rotors are either stall or passive pitch controlled, the latter type being more common.

The DP is of the RO type, which is the most suitable for small- and medium-scale applications for the production of potable water from the sea [1]. This technology is quite mature today, presents relatively low operating costs and specific energy consumption, as well as fast start up and stop times [6,9]. RO plants come in a great variety of production capabilities. In this study, a range of alternative plants has been considered, with nominal