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A synergic integration of desalination and solar energy systems in stand-alone microgrids

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ABSTRACT

In this study, we investigated the possible synergies between desalination technologies and solar energy in a remote energy system modelled as a small-size island with the goal to increase system sustainability. The solar systems implemented are photovoltaic panels (PV) and a Concentrating Solar Power system coupled with an Organic Rankine Cycle (CSP-ORC). For the desalination both Reverse Osmosis (RO) and Multi-Effect Distillation (MED) are considered. We found that the simple installation of PV is a valuable option to decrease electricity costs in remote context presently based on Diesel fuel generators but it struggles with achieving high penetration of Renewable Energy Sources (RES) (> 40%) due to the intermittent nature of solar energy and the consequent need for large batteries. The installation of a CSP-ORC allows further reducing the fossil fuel consumption thanks to the use of thermal energy storage and the effective integration with a MED facility. The results show that both solar energy technologies allow a considerable cost saving compared with the traditional solutions based on diesel generation. The most promising solution is a hybrid integration of all four above mentioned technologies, enabling RES penetration over 75% with > 10% of cost savings.

1. Introduction

Nowadays most of small islands around the world are still basing their electricity generation on fossil fuels, especially Diesel oil. In fact, in most cases grid connection to the mainland is practically unfeasible or too costly, so that the energy needed to cover the community requirements is produced locally using Diesel oil fueled internal combustion engines with several drawbacks. Since Diesel oil supply has generally a high cost in remote locations (0.8–1.2 USD/l) and diesel generators are often forced to part-load operation throughout the year, the resulting levelized cost of electricity (LCOE) is on average considerably higher (0.3–0.6 USD/kWh) than the one on the mainland [1]. Other relevant shortcomings are related to the strong dependency from an external source, with price fluctuations and uncertainty of supply, and of course the environmental concerns associated to diesel engines emissions.

Problems related to Diesel oil exploitation for electricity generation are even more significant in case of scarcity of fresh water, a situation that may occur in many islands. Since the import is frequently an expensive option, fresh water is usually produced locally from seawater using desalination processes which require considerable amount of electricity [2]. As a consequence, a relevant share of electricity is spent in water desalination, like in the case of Canary Islands where depending on the season from 5 to 30% of electricity is used to power reverse osmosis (RO) plants [3]. The sum of all these factors leads to high expense for fossil fuel import, which in island communities accounts for a value typically ranging from 8 to 20% of GDP, a high value compared to the average one on mainland (4.5%) [4,5].

A possible option to be considered is the installation of power generators based on Renewable Energy Sources (RES). Thanks to the massive deployment of certain technologies (photovoltaic above all), in the last decades a considerable cost reduction has been observed making these technologies competitive with conventional fossil fuels generation. The competitiveness and the advantages are more evident in remote locations, where the cost associated to energy production from Diesel oil is high.

A lot of research and demonstration projects have been conducted to bring RES in islands, with several successful examples [6]. Real cases show that the introduction of solar photovoltaic (PV) or wind turbines (WT) into existing grids historically based on Diesel engines allows considerable fuel and money savings during the project lifetime [7]. However, the most implemented technologies (PV and WT) are based on intermittent sources. Discontinuous and random production poses severe technical issues that are even more challenging to be managed in limited capacity grids. El Hierro, which claims to become the first 100% renewable island, exploiting its wind resource, has experienced several

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problems to exceed 30% penetration of RES. The objective will be reached thanks to a hydro-pumped storage system exploiting the peculiar topography of the island [8]. The trend is confirmed in many islands and it is very rare that more than half of energy is produced by RES, even in presence of energy storage systems [7].

One possibility of increasing the dispatchability of RES has been studied by exploiting the potential synergy with desalination. Powering the desalination plant with energy coming from RES in island context leads to both peak shaving and fresh water production cost reduction [1,9]. In this paper we focus on solar energy as RES comparing the advantages attainable with the introduction of two different solar power plants, namely PV and Concentrating Solar Power (CSP) plant. Despite of high installation costs, CSP technology is expected to reach higher RES penetration thanks to the possibility of efficiently storing thermal energy, thus decoupling the electricity production from solar energy availability. Another potential advantage is related to possible synergies with Multi Effect Distillation (MED) plants; this technology, used to produce fresh water, requires huge amount of low-temperature thermal power during operation which could be efficiently produced by the CSP in cogenerative configuration. This option, already investigated for other kinds of Combined Heat and Power (CHP) plants [10], could lead to a reduction of total fossil fuel consumption, potential cost savings in electricity generation and a better exploitation of the solar resource [11].

With the aim of performing a fair and realistic comparison between the two technologies, the whole hybrid system operation is simulated using a rolling horizon approach based on the Unit Commitment problem. Operational costs are assessed simulating a whole year by means of an optimization model which exploits a given set of units, both power generators and desalination plants, to cover the electricity and fresh water demand at the least feasible costs [12]. This is an important novelty compared to other recent studies [10,11,13], in which the performances of the system are evaluated only at nominal or average load and do not take into account the yearly variability of water and electricity demand, the RES productivity and the presence of electric or thermal storage systems.

2. Test-case description

The test-case used to assess the different microgrid (MG) configurations consists of a small island community. The MG is responsible to satisfy both electricity and potable water needs. Due to the lack of comprehensive studies and data availability about one single real case, we built synthetic time series of the demand of both electricity and potable water considering both realistic weather data and a seasonal variability of the island inhabitants. We assumed the weather data of Tenerife (Canary Islands) and used as reference SWEC[1] hourly dataset. In addition, we assumed that island occupancy ranges from 8400 in low season (October–May) up to a peak of 12,000 inhabitants in high season (August).

We split electricity demand per capita in two different terms: basic needs (BN) and air conditioning needs (ACN). The basic needs comprise the domestic and the commercial users, the public lighting and the public buildings loads. We assumed a daily pattern common to most of developed countries, with two demand peaks at the middle and at the end of the working day and a lower consumption during nocturnal hours [14] as reported in both Fig 1.b and c. The daily base electrical load profile is obtained imposing an average electricity consumption of 5 kWh_{el}/(day person) as representative of a developed country. Fig. 1.a depicts the hourly electrical load and the average monthly load along one representative year. The hourly demand peak is in summer and it is about 7 MW_{el} because of the increase of island inhabitants as well as of the presence of air conditioning load. In order to simulate the variability of electricity demand, a ± 40% random deviation is added for the basic needs trend while the air conditioning load variation is exclusively due to ambient temperature change. Air conditioning need (ACN) increases proportionally with the ambient temperature when it is higher than 26 °C while vanishes at lower temperatures and its maximum value is assumed equal to the 50% of the BN yearly peak. As result, ACN represents the 12% of electrical energy needs in summer months and 5% on a yearly base. Fig. 1.b and c depict the data variability for January and July reporting for each hour of the day the monthly minimum, the average and the maximum values together with the 1st and the 3rd quartile values of the distribution. The resulting total annual electricity demand (not including water related requests) is about 16.9 GWh.

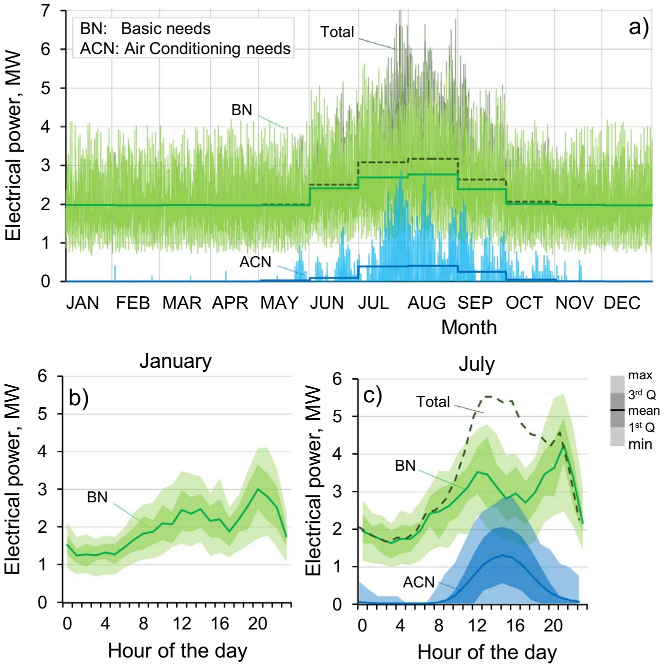

Fig. 1. Trend of electricity consumption: a) hourly variability for the basics needs (light green) and the air cooling load (light blue) and monthly average values. Hourly variability range for the months of January (b) and July (c). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

The daily potable water consumption pattern per capita has been derived from [15] considering that most of the consumption is related to residential and commercial sector (restaurants and hotels). We assumed a daily average consumption equal to 500 l/(day person), with a small seasonality related to ambient temperature. A random variation of ± 10% is added in order to examine a more realistic case. The resulting total annual water request is about 1.600.000 m^3 and the

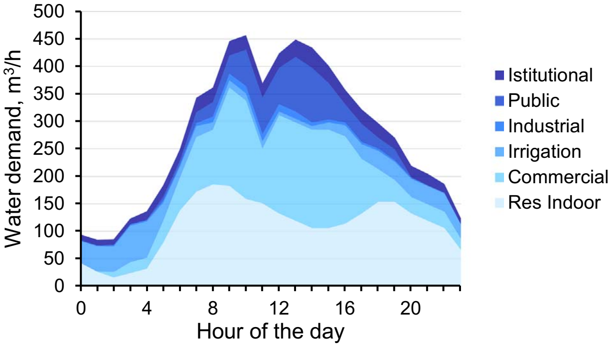

Fig. 2. Daily pattern of community water consumption in the 15th of August.

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[1] SWEC (Spanish Weather for Energy Calculations) data set from https://energyplus.net/weather.