Desalinated Water and Power for a Seaside Hotel: A Case Study using Off-grid Solar and Wind

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Abstract A hybrid combination of solar and wind energies for a remote seaside hotel is analyzed. More specifically, a hotel in Hammamet, Tunisia, powered by photovoltaic panels and a wind turbine is evaluated, with water generated by desalination using reverse osmosis. This isolated accommodation establishment is off-grid, having to produce its own drinking water, energy for cooking, lighting, etc. The power balances in these PV-wind-desalination systems is strongly influenced by the sunshine, the wind, and the demand. Based on an analysis of needs, the system is then sized. The variable nature of renewable energy sources, combined with unpredictable changes in load, require the simultaneous implementation of high power and high energy density storage systems. Thus, an storage system by lead-acid batteries for power and an elevated storage tank is considered, developing an autonomous microgrid connected to a variable charge. The system was validated by simulations (performed by Matlab/Simulink), based on data from the location, allowing us to predict the dynamic behavior. The simulation results validate the performance of the system.

Keywords: Renewable energy; Water supply; Off-grid systems; Reverse Osmosis; Seawater desalination; photovoltaic, wind turbine

1. Introduction

The objective of this work is to develop a supply system for a hotel with renewable energy, aiming to show that it is possible to change fuel power for renewable power production for water and power needs in a touristic installation. In reality, the availability of energy and the supply of conventional energy is not always possible in remote regions or small islands (Bull, 2001); on the one hand, because of the difficulties in supplying fossil fuels, and on the other, because the network does not exist or the available energy is not sufficient to power a desalination plant. Today, most isolated settlements requiring the production of drinking water use fossil fuels, so it is very interesting to switch to renewable energy production (Palacin, 2011, Reilles et al., 2019).

Furthermore, the demand for freshwater is increasing due to tourism, which is normally concentrated at times when the availability of renewable energy is high, particularly in the case of solar energy. The operation and maintenance of renewable energy systems are normally easier than conventional energy ones, so they are suitable for remote areas. Lower production costs of renewables and higher fossil fuel prices could make it possible to make seawater desalination competitive through renewable energy for hotels or businesses that would require efficient energy systems at lower costs (Reilles et al., 2019).

This paper then summarizes the design and analysis of a system to produce water and power for a remote hotel, to be fully provided by water from reverse osmosis desalination, and power by a combination of wind and solar energy.

2. Case Study

2.1. Resort studied

The case study is a hotel in Hammamet, Tunisia (See Figure 1): it is a 4-star hotel with a capacity of 280 guests, and is located at 36° 24’00’’North, 10° 37’00’’ East, so power and water can be produced in place. The data from this hotel will be used as a reference for the meteorological conditions required for the wind turbine and photovoltaic panels, as well as for energy and water consumption estimates. They will be the source for our system dimensioning. Throughout the year, there is very little diurnal wind variation (as would be expected with such topography), while the tropical phenomenon of large diurnal pressure variation is so pronounced that it almost eclipses the month-to-month pressure variation (GWEC, 2020).

Figure 1: Hotel resort for the case study

2.2. Desalination

Drinking water is produced in the hotel using a reverse osmosis desalination plant. This is membrane-based systems that allows only water molecules to pass through, using high pressures to compensate for osmotic differences. In conventional osmosis units, there are three filters and one membrane (Qasim et al., 2019). The pre-filter and the anti-sediment filter take care of the solid particles present in the raw water. The charcoal filter retains all the elements that contribute to the bad smell or unpleasant taste of water, because of such chemicals as chlorine or pesticides. Finally, the membrane filters all the rest: nitrates, limestone, and other bacteria and viruses, to preserve only the molecules of water.

For the reverse osmosis size expected in this installation, each liter of reverse osmosis water requires around five liters of seawater, with the rest returned to the sea. This extra water is used so as not to retain contaminants in the system, and to clean the membrane regularly to improve the energy performance (Hau, 2000).

2.3. Power supply

The electrical production will be carried out using a large installation of solar panels on rooftops and parking area, combined with one wind turbine to provide power when the sun does not shine sufficiently, and some batteries as backup.

For the wind generator, given its good performance and robustness, we choose to use a standard wind turbine consisting of a three-blade rotor (Navigant, 2020). The power output is estimated (Ackermann, 2005) to be proportional to the kinetic energy of the air passing through the effective disk area of the machine (S):

$P_w=0.5*0.59*\rho*v^3*S$

where ρ is the air density, and v the mean wind speed. It is technically more interesting to install a single one large wind turbine, to have a better surface of exposure to the wind.

As regards to the photovoltaic panels, polycrystalline silicon panels are selected, as they are currently less expensive than mono-crystalline silicon ones.

2.3. Energy storage

The storage of energy will take two forms:

- The first form is a bank of lead-acid batteries (Razelli, 2019, Xiaoxi, 2013). Electrical storage by the use of the battery is expensive, but unavoidable to ensure power supply on calm nights. The storage capacity will be reduced as much as possible.
- The second means of storage is by producing and storing drinkable water when there is an excess of energy. The storage of water can guarantee the equivalent of a large amount of energy at a low price.

3. Sizing of components

To size the system the methodology proposed is based on first estimating the daily water consumption of the installation. This will be used to estimate the daily power consumption by combining the power required to desalinate the water with other uses of electricity. To power the installation a wind turbine would be selected, that will be complemented with solar panels. A simulation with hourly data of power production and consumption on the planned location would then be used to size the energy storage.

The application of this methodology to our case study is now summarized.

3.1 Estimation of water consumption

To estimate the water and electricity needed for the daily used in the hotel, the water need was evaluated from equivalent installations in similar locations: see figure 2. Based on that, it was estimated at mean capacity each resident used 1.6 m^3 each day. As the resort is designed for a peak capacity of 280 residents, then 448m^3/day would be needed for drinkable water

In addition, the swimming pool was assumed to require 120m^3/day, whereas garden watering uses a mean value of 12m3/day and restaurants and other installations would require 22.4m^3/day. These water uses have different quality and salinity requirements, but for the sake of simplicity they are aggregated Q=602.4 m^3/day

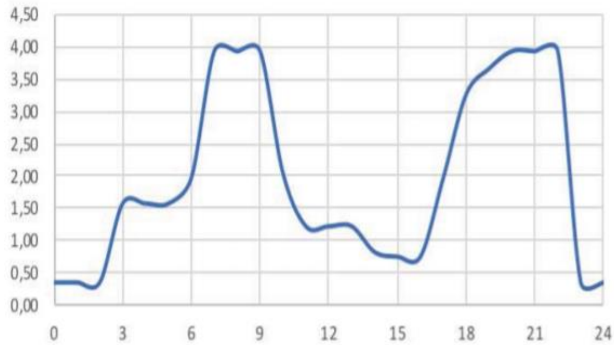

Figure 2: Estimations of the water consumption in a typical day

Table 1. Summary of Water Consumptions

Water consumption	*Quantity (m^3/day)*
Rooms use	448
Swimming pool	120
Garden green watering	12
Restaurants and bars	22.4
Total	**602.4**

3.2 Desalination

Based on the water requirements evaluated in previous subsection it was decided to combine two Reverse osmosis systems from different manufacturers and different characteristics to achieve the desired output, and provide water with different qualities for different uses and adapt to variations in water demand and maintenance of equipment. Thus, the system would be oversized to ensure that there is always available water. Based on the local market a Prominent system (Dulcosmose – Pro1000TW) was combined with the Veolia system (Sirion sea water D-360-PX). The PRO1000TW system allows $10m^3/h$ to be processed for an average energy consumption of $1.1KWh/m^3$. The D-360-PX can treat $14.85m^3/h$ and consumes on average $3.16kWh/m^3$. Using mean values from both RO systems, $2.13kW/m^3$ would be needed, which corresponds to 1283kWh/day for the complete installation.

3-day water storage is assumed, giving a storage capacity of $450m^3$. This storage can stop water production if there is not enough wind or solar power for a few days.

3.3 Estimation of power consumption

In addition to the power required by the water system, the power required for other uses was estimated based on equivalent installations in similar locations (see Figure 3). Thus, based on a mean use of 22.87kWep by resident by day, and the equivalence of 1kWh=2.5kWep, it was estimated that 2562 kWh/Day are required.

3.4 Sizing of Electrical components

The previous analysis has shown requirements of 3845 kWh/day. Given the limitation in available space in rooftops and parking area and the good wind resource, it is decided that power production should focus on the wind turbine, with the solar panels covering the power required for drinkable water and basic power uses. A wind turbine is then selected from the local market that should cover in a typical day most of the power consumed. One with a peak power of 540 kW is selected, that would produce an average of 3480 kWh/day when considering the wind distribution in the area (GWEC, 2020)

To size the PV system using the mean irradiation of Ei=5.94 $kWh/m^2/day$, the power produced should fulfill P_c>120kWep. This can be obtained using 343 panels of standard 350W oriented to the maximum of radiation in the location. Each of these panels require around $1.5m^2$, using approximately $530m^2$.

Sizing a storage system means finding the optimal size, considering production and possibly forecasts, to maximize (or minimize) predefined performance criteria. A battery used with solar panels, or a wind turbine, is a slow battery discharge (also called solar battery). These batteries are specifically designed for solar and wind applications. They do not have the same characteristics as a car battery; for example, they discharge more gradually and better withstand frequent shallow discharges. For a wind, solar or hybrid solar-wind installation, the capacity of a solar battery is expressed in Amperes Hour (Ah), which means the total flow of battery power in a given situation (Razelli, 2003). The storage of electricity is designed to provide aprox. 2500kWh/day.

Table 2: Summary of Powers

Power for water	1283
Power for other uses	2562
Wind Energy (145 kWp)	3480
Solar Panels (330 kWp)	1446

Table 3: Summary of Storage

Storage of water	$450m^3$
Storage of Electricity	2500kwh (1 day)

Table 4: Estimation of Costs

System	Costs (K€)	Maintenance (K€/year)
Wind turbine	587	9
Solar panels	228	8
Reverse Osmosis	152	10
Battery	900	8
Water tank	14	2
Installation and Other	188	4
Total	**2059**	**41**

4. Validation

A cost analysis was developed to evaluate the acquisition, installation and maintenance costs for the different components. They are summarized in Table 4.

To evaluate the technical feasibility some simulations were carried out to study the influence of the parameters and their variation on the behavior of the system. Simulink was used for this. The basic characteristics of the PV generator, wind turbine, and converters (DC-DC, AC-DC, bidirectional DC-DC, and DC-AC) were modeled and simulated. The modeling and simulation of the (SS) by a lead-acid battery in a PV -battery-direct load scenario for an isolated winter charge was also performed.

An example is now summarized: Figure 3 presents the evolution of the energy stored in the battery bank during the month of February. The details of the Power balance for one day is presented in Figures 4 and 5. It can be seen that the system is correctly sized to ensure power availability, with battery storage required to provide power mostly between 18 and 22h.

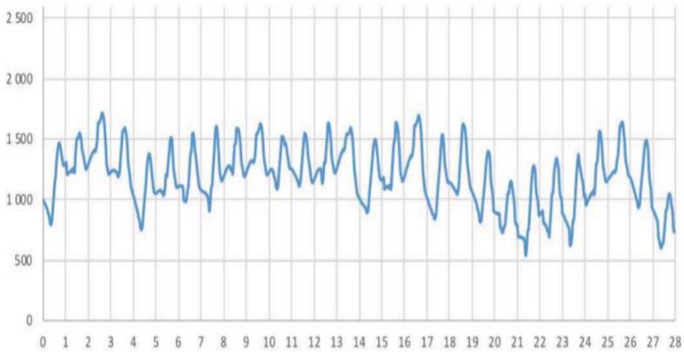

Figure 4: kWh stored in the battery bank

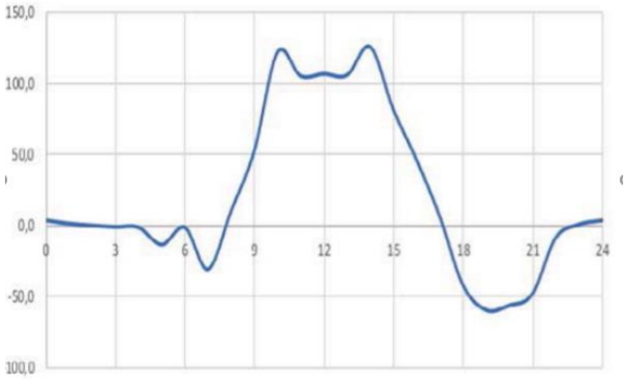

Figure 5: power balance in a typical day

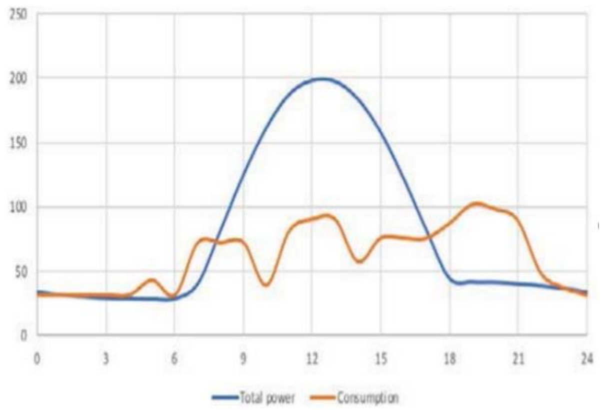

Figure 6: Average estimation of daily power production and consumption (kW vs. hour of the day)

The simulation results in Figure 4 to 6 show the efficiency of the controls used in order to maximize production, balancing demand and supply. Performance battery dynamics to react to the intermittence of PV-wind production (compensation) and sudden variations in the load, validated by simulation, highlight the importance of Energy Management Systems in the micro-grid. The simulation results show good behavior in the presence of climatic variations. These variations made it possible to demonstrate the good efficiency of maximum power tracking systems of the PV generator. Satisfactory results have also been obtained for the wind turbine chain.

5. Conclusions

The studied system highlights the equipment required in a cogeneration structure supplying a load when isolated or remote from the local network. In order to better understand the interaction between the different subsystems, a detailed study highlighting their performances was adopted. To achieve the objective of the study, we considered several aspects: First of all, a rich and varied bibliographic study of the subject by situating it in a social, economic and scientific context was established. This allowed us to take into account questions related to environmental problems caused by the use of fossil fuels on the one hand, and the supply of isolated or remote areas on the other. Then, the modeling of solar and wind energy generators, as well as their static converters (boost chopper and rectifier), necessary for the conversion solar and wind power, respectively, is mentioned.

An investigation into the choice of storage system and lead-acid battery. The study, modeling and simulation of a PV-battery-DC load scenario has been carried out. The simulation results are conclusive with respect to the hypothesis approach and the literature review, thus validating the dynamic performance with the lead-acid battery. In order to design an efficient hybrid power generation system, an overview of the sizing, main sub-components (PV generator, wind power and battery) hybrid system have also been developed.

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