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Water and energy self-supply in isolated areas through renewable energies using hydrogen and water as a double storage system

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ABSTRACT

Because of their geographical isolation, many areas depend mainly on imported fossil fuels for their water and energy production. In this context, the Canary Islands are one such remote area. Due to the topography of the islands, there are numerous isolated areas on each of the islands far from the major population centres. These are known as 'islands within islands'. The main aim of this paper is to determine the feasibility or otherwise of supplying from renewable energy sources both the energy and water needs of the 219 inhabitants of El Risco located in the municipality of Agaete on the island of Gran Canaria (Spain). For this purpose, the potential use of existing renewable resources in this isolated area has been analysed, using hydrogen as energy vector. A reverse osmosis (RO) plant is integrated into the system to ensure water self-sufficiency and, in turn, constitutes a double storage system (hydrogen-water). Based on the results obtained from the study, the technical feasibility of the system is confirmed, with an annual energy production of 1,743,031 kWh/year compared to a consumption of 672,314.32 kWh/year, as well as a potable water production volume of 46,546.80 m^3/year obtained from the RO plant. The reliability of the system is confirmed in the economic analysis, obtaining a renewable electricity cost of 0.107 €/kWh compared to 0.18 €/kWh when using conventional electricity.

1. Introduction

It is widely recognised that the current energy system is unsustainable given the finite nature of the fossil fuels which form its basis. The fact that humanity consumes in just a single year the same amount that nature required a million years to create should be sufficient to make clear the rapidity at which fuel reserves are being exhausted [1].

Not only are these fuels an important contributing factor to the greenhouse effect and acid rain, but they also drive deforestation and are the cause of social tensions and even wars between countries who endeavour to ensure their energy supply while having to contend with continued fluctuations in the price of oil [2].

This problem is aggravated in geographic regions which are characterised by their dependence on external-sourced energy. Many of these regions, principally but not exclusively islands, can be considered isolated areas as they depend completely on the import of fossil fuels for energy production [3].

The outermost regions of the European Union, one of which is the Canary Archipelago (Spain), are a clear example of the type of situation considered in the present study. In our particular case, the topography of Gran Canaria island is highly complex and diverse as the result of its geological formation, its subsequent evolution and its climatological characteristics. In consequence, there are numerous small, semi-remote villages - whose inhabitants work principally in agriculture, cattle-farming or rural tourism - located at some distance from the main sources of water and energy (which, in the case of energy, is mostly imported from mainland Spain).

Such remote areas on Gran Canaria include, amongst many others, El Risco, Casas de Veneguera, El Horno, Fagajesto, Chira, La Culata, Artejevez, Ayacata, Artenara and Trejo [4]. These have been described as 'islands within islands' (geographically isolated areas in a geographically isolated archipelago). This new concept arises from the weaknesses which on occasions manifest themselves in the energy transmission line when anomalous situations occur that generate considerably higher energy demand (whether due to tourism, industry or seasonal fluctuations). These villages are therefore clear examples of situations which could benefit from the implementation of distributed generation or microgrid systems.

Presently, a series of different approaches are being investigated in an attempt to reduce the worldwide dependence on fossil fuels. One of these approaches involves the use of renewable energy sources, creating scenarios that are environmentally clean and respectful and that consequently avoid the emission of huge amounts of contaminating gases

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[5].

Systems such as those described in studies by Mehdi Baneshi et al. [6], Golbarg Rohani et al. [7], Barun K. Das et al. [8] and Normazlina Mat Isa et al. [9] employ renewable energies stored in batteries and supercapacitors. Other renewable systems, as is the case of Bahram et al. [10], Sihem Nasri et al. [11] and Nicu Bizon et al. [12] avoid conventional storage methods and instead use hydrogen as energy vector, using it as a means of storage to again produce electricity with fuel cells. Systems can also be found with a symbiosis between these two storage types, as is the case of Anand Singh et al. [13].

All these cases, and particularly those which store hydrogen, have resulted in major improvements and a high degree of self-sufficiency. However, the aim of the present work is not only to supply the energy demand with renewable-sourced energies, but also to guarantee at the same time self-sufficiency in terms of meeting the water demands of the population. For this latter purpose, a reverse osmosis (RO) plant has been included in the proposed system. As such, the innovation of the proposed system lies in its use of both water and hydrogen as a double energy storage system.

With all of the above in mind, the present study analyses the technical feasibility of a distributed generation system which uses wind and solar technologies in a remote region on the island of Gran Canaria (Spain), called “El Risco” (see Fig. 1).

The main basis of this feasibility analysis is undertaken with the “Hybrid Optimization of Multiple Energy Resources” (HOMER) microgrid modelling software [14]. In addition, a simulation is undertaken in parallel of the RO plant using the Reverse Osmosis System Analysis (ROSA) design software [15]. In this way, both types of demand (energy and water) are covered and a double storage system employed (hydrogen and water). The above is explained in greater detail in sections 3 and 4 of the present paper.

‘El Risco’ is considered a remote area in view of its infrastructure and economy, as well as its location. This area has been chosen as it is one of the furthermost regions on the island from the capital city of Las Palmas de Gran Canaria (47.3 km). Compared to other isolated regions on the island its population is relatively high, and its climatic conditions (low rainfall, high percentage of sunny days and exploitable wind conditions) [16] and location (at ground level of a ravine) mean that the proposed system could be installed nearby to take advantage of the excellent wind conditions in the surrounding area, making it an optimal area for implementation of the system.

At the present time, the energy demanded by El Risco is supplied conventionally by the island grid from the Juan Grande plant, located some 92 km away, where more than 80% of the energy is generated from fossil fuels. The water demand is met through the desalination plant in Gáldar, 25.8 km away.

The variation in electricity demand over the course of a day for the population of El Risco shows maximum consumption levels during the middle hours of the day and the early hours of the evening. Fig. 2 shows a comparison of the different power peaks and troughs over a 24-hour period on the fifteenth day of three different months in 2014.

The annual load curve, with the maximum powers recorded in each month, is shown in Fig. 3. Both Figs. 2 and 3 were generated using values obtained from the database of Red Eléctrica de España, Spain's electricity system operator.

2. Description of the system

The proposed system comprises both wind and photovoltaic renewable energy technologies, and is completed with an electrolyser, a fuel cell and a hydrogen storage tank. In addition, an RO plant has been included to supply water to the local population.

The aim is to ensure the supply of the 672,314.32 kWh/year consumed by the 219 inhabitants of the area as well as to meet the water demand of 15,987 m^3/year, using renewable-sourced energies and employing a double storage system (hydrogen and water). By these means, the yearly emission into the atmosphere of some 664,010.18 kg/CO_2 could be avoided, a total of 49,078.93 €/year could be saved in terms of electricity (production and transport costs), as well as 10,071 €/year with respect to meeting water demand.

Schematically, the system has the configuration described in Fig. 4.

2.1. Operating modes

The operating modes that describe the system are essentially as follows [17], and are shown in Table 1:

- The system consists of an electrical energy generation plant using wind and solar irradiation as prime energy resources. During periods of high electricity demand, the energy that is produced is fed into a stand-alone grid to supply the energy needs of the population of El Risco.
- During low demand periods, the plant will use the surplus energy generated to produce hydrogen by means of water electrolysers. In addition to hydrogen production, when enough excess energy exists the system will also produce potable water in an RO desalination plant.
- The hydrogen will be stored and fuel cells (FC) will be used to produce electrical energy when the wind and solar conditions are insufficient to directly meet the energy demand of the population [3,18,19,and 20].

The primary purpose of the system is to meet the energy needs of the population. However, if the system is also capable of satisfying potable water requirements, the population can be become practically self-sufficient. Bearing in mind the climatic conditions of the Canary Islands, the available renewable resources (mainly wind) fluctuate considerably and so, ex ante, it is assumed that even the most optimized system will have a significant surplus of energy. This excess energy could be used for water desalination, either seawater extracted from the

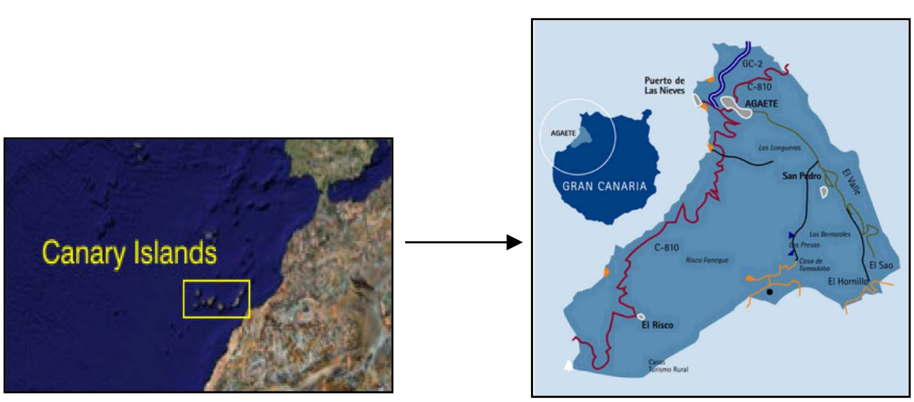

Fig. 1. Map of Canary Islands, Gran Canaria and ‘El Risco’.