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# Analysis of a pumped storage system to increase the penetration level of renewable energy in isolated power systems. Gran Canaria: A case study

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ABSTRACT

A significant number of islands have been forced to restrict the penetration level of renewable energy sources (RES) in their conventional electrical power systems. These limitations attempt to prevent problems that might affect the stability and security of the electrical system. Restrictions that may apply to the penetration of wind energy can also be an obstacle when meeting European Union renewable energy objectives. As a partial solution to the problem, this paper proposes the installation of a properly managed, wind-powered, pumped hydro energy storage system (PHES) on the island of Gran Canaria (Canary Islands). Results from a dynamic model of the island's power system show that the installation of a pumped storage system is fully supported in all circumstances. They also show that the level of wind penetration in the network can be increased. These results have been obtained assuming that two of the largest existing reservoirs on the island (with a difference in altitude of 281 m and a capacity of aprox. 5,000,000 $m^3$ each) are used as storage reservoirs with three 54 MW generators. Likewise, the ability of such facilities to contribute to the stability of the system is shown. This type of installation can reduce fossil fuel consumption, reducing $CO_2$ emissions. Moreover, not only can the PHES improve wind penetration level, but it also allows the number of wind farms installed to be increased. Regions with geographically suitable sites and energy problems similar to those on the Canary Islands are encouraged to analyze the technical and economic feasibility of installing similar power systems to the one in this paper. Such systems have an enormous, unexplored potential within the general guiding framework of policies promoting clean, renewable energy.



## 1. Introduction

Wind turbines, photovoltaic cells and other renewable energy systems are currently increasing their rated power all over the world. Large power systems, such as the European interconnected power system (UCTE/CENTREL), can withstand the high penetration levels of renewable energy plants.

However, isolated systems, such as those on small islands, have greater difficulty increasing penetration level for safety reasons [1]. This is the case of the island of Gran Canaria (Fig. 1).

Geographical fragmentation, the distances from large areas of energy production and consumption, and the absence of conventional energy resources lead to a strong dependence on fossil fuels. However, the Canary Islands have abundant renewable energy sources available, mainly wind and sun. Wind resources are especially high in intensity and show low variability [2].

Each island has an isolated small-to-medium-sized power system [3]. A number of serious problems can appear when trying to maximize the percentage of electrical energy load that can be covered by directly feeding wind and photovoltaic power energy into a power system of this size. At high levels of RES penetration, the variations in the generated power (due to variations in wind speed and solar radiation) cause an imbalance between the power generation and power load in the system, increasing frequency and voltage variations which could lead to dangerous operating conditions [4].

RES generation must be limited to avoid problems that could affect the security and stability of the electrical power system [5,6]. Local authorities, as a result of these technical requirements, have imposed a restriction on the exploitation of the available wind potential through wind farms connected to the power system at just 411 MW of installed capacity and 46 MW of photovoltaic power [7].

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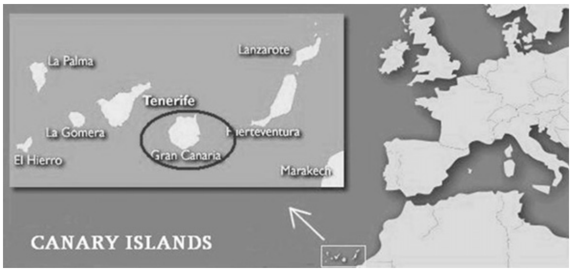


**Fig. 1.** Geographical location of the Canary Islands.

To integrate those amounts of wind and photovoltaic power safely, and minimize possible limitations, the installation of a pumped storage system (PHES [8–11]) is planned on the island. This issue has been investigated by other researchers, who have concluded that the project is economically feasible and also necessary for the energy balance of the power system [12,2]. Those studies have led public administrations to become aware of the importance of this project, and its installation is going to be considered [7,18]. The project consists of a 162 MW PHES plant that could be in service by 2016.

Before deciding to install such a system, it is necessary to study the ability of the planned power system to integrate the new PHES plant, and the feasibility of reaching the final goal of increased renewable penetration levels [13–16]. This paper presents a method for developing a model to study the effects of the pumped storage system on the RES penetration level and other aspects of the power system. The model was applied to the island of Gran Canaria.

This model was built using one of the most powerful available open source codes for analyzing power systems, PSAT (Power System Analysis toolbox) [17] which works under MATLAB.

## 2. Gran Canaria power system model

The power system of the island of Gran Canaria is composed of two thermal power plants with a total power of 1343 MW [18] (Table 1).

Regarding the transmission system, there will be 460 km of lines and 42 substations operating by the end of 2016, according to current planning. The power generation and distribution systems are owned by Endesa, while Red Eléctrica de España is the system operator (SO) [3].

### 2.1. Power system one-line diagram

Fig. 2 shows the planned isolated power system of the island by the end of 2016. The one-line diagram includes all substations with their names (Arinaga, Carrizal, etc.), all transmission lines (overhead and underground), all power transformers, and all generators.

Each element of the network was modeled using standard models [19]. For transmission lines, a $\pi$ model without conductance; for the capacitor banks, a three steps bank model; and loads were modeled assuming a $\cos(\varphi) = 0.9$. Finally, power transformers were modeled as two-winding transformers, which connect the 200 kV to the 66 kV voltage levels.

### 2.2. Thermal power plants

Each unit of the two thermal power plants is modeled by a typical four-block system as shown in Fig. 3.

**Table 1**
Conventional power generation units in Gran Canaria by the end of 2016.

| Unit name | Capacity (MW) |
|---|---|
| JIN-1, STEAM 1 | 33.15 |
| JIN-2, DIESEL 1 | 12.00 |
| JIN-3, DIESEL 2 | 12.00 |
| JIN-4, DIESEL 3 | 12.00 |
| JIN-5, STEAM 2 | 40.00 |
| JIN-6, STEAM 3 | 40.00 |
| JIN-7, GAS 1 | 23.45 |
| JIN-8, STEAM 4 | 60.00 |
| JIN-9, STEAM 5 | 60.00 |
| JIN-10, GAS 2 | 37.50 |
| JIN-11, GAS 3 | 37.50 |
| JIN-12, DIESEL 4 | 24.00 |
| JIN-13, DIESEL 5 | 24.00 |
| TIR-1, GAS 1 | 37.50 |
| TIR-2, GAS 2 | 37.50 |
| TIR-3, STEAM 1 | 80.00 |
| TIR-4, STEAM 2 | 80.00 |
| TIR-5, GAS 3 (CC 1) | 75.50 |
| TIR-6, GAS 4 (CC 1) | 75.50 |
| TIR-7, STEAM 3 (CC 1) | 79.65 |
| TIR-8, GAS 5 (CC 2) | 75.50 |
| TIR-9, GAS 6 (CC 2) | 75.50 |
| TIR-10, STEAM 4 (CC 2) | 79.65 |
| TIR-11, GAS 7 (CC 3) | 75.50 |
| TIR-12, GAS 8 (CC 3) | 75.50 |
| TIR-13, STEAM 5 (CC 3) | 79.65 |

- Synchronous machine

A sixth order model was selected [20]. It is obtained assuming the presence of a field circuit, an additional circuit along the d-axis and two additional circuits along the q-axis. The system has six state variables (rotor angle ($\delta$), rotor speed ($\omega$), q-axis transient voltage ($e'_q$), d-axis transient voltage ($e'_d$), q-axis subtransient voltage ($e''_q$), d-axis subtransient voltage ($e''_d$)).

- Unit transformer

A two-winding transformer is used as the connection between the generator and the power system. A resistance-reactance series model without iron losses has been used.

- Automatic voltage regulator

Automatic Voltage Regulators (AVRs) are the primary voltage regulation for synchronous machines. PSAT allows three simple different types of AVRs to be used. The AVR Type II was chosen, which is the standard IEEE model 1.

- Turbine governor

Turbine Governors (TGs) are the primary frequency regulation of synchronous machines. A standard model of PSAT was used.

### 2.3. Wind turbines

Local authorities have established operational requirements for wind farm operation [21]. For example, when a shortcircuit occurs, the turbines must withstand a very hard voltage dip. Due to this legislation, the most suitable wind turbine technology is the doubly-fed induction generator (DIFG) [22] which is implemented in PSAT [23] (Fig. 4).

The next step must be to calculate the value of the parameters for all the models above. Many technical publications were used to