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Coupling of a Solid-Oxide cell unit and a linear Fresnel reflector field for grid management

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Abstract

Recent analyses on energy scenarios for countries with high contribution of intermittent renewables point out that electricity generation from solar and wind energy may exceed the overall electricity demand during a large number of hours per year (that include peak periods). Thus, large-scale electrical –energy storage systems are required for grid balancing. Hydrogen production through solid-oxide electrolysis cells (SOEC) stands for promising power storage systems due to its high capacity and wide variety of applications. SOEC operates with steam in the range of 600-1000 ºC, which, in this work, is supplied by a concentrating solar system. Based on its simplicity and low cost of the components, a linear Fresnel reflector coupled with castable ceramic thermal energy storage system was selected. Thermal oil was retained as heat transfer fluid avoiding phase change through the solar receiver. The heat is stored during the day for later use by the SOECs.

The proposed hybrid plant, located in Seville, Spain, is analyzed under two scenarios. In the first one, the Solid-Oxide unit is only used as steam electrolyser producing hydrogen that is directly sell to a hydrogen bus refueling station. In the second case, the device operates either as electrolyser or fuel cell, generating hydrogen that is stored and later used to produce electricity during peak periods. The capacity of the plant operating under both scenarios has been evaluated as a function of the storage capacity.

Keywords: Solid-Oxide cell; Linear Fresnel reflector; Hydrogen; Grid management.

1. Introduction

Environmental concerns and limited resources of fossil fuels have stimulated energy policies pursuing large share of renewable energy (RE) within the power and transport market. The European Commission established mandatory targets to be achieved by 2020 for a 20% overall share of RE in the energy mix

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and a 10% share in the transport sector [1]. Within this framework, the last Spanish government established policies that have resulted to levels of 39.4 % of RE share along the last 12 months [2]. However, the electricity from RE resources is not constant and reliable due to their sensitive response to local weather conditions. To level out the variable generation of energy, large-scale electrical-energy storage is required [3–5]. Whereas batteries, compressed air, flywheels or capacitors are suited for the short-term storage of electricity, long-term storage could be realized with hydrogen as an energy vector through the so-called power-to-gas (P2G) plants [6].

With P2G, excess electricity is converted into hydrogen by water electrolysis. This hydrogen can be stored in pressurized tanks and, when needed, it can be reconverted into electricity with fuel cells or hydrogen combustion engines. Besides its use as energy storage for electricity, hydrogen can be used as fuel for transport applications, as a raw material for the chemical industry, or for the synthesis of various hydrocarbon fuels such as methane. Additionally, a certain percentage of hydrogen could be directly fed into the gas distribution system; furthermore, there should be no limitations, whereas hydrogen is previously converted to methane [7–9]. Since 1990, more than 41 international power-to-gas (P2G) pilot plants have been installed and run producing hydrogen for Grid balancing [10].Most projects integrates alkaline or proton exchange membrane (PEM) electrolyser. These kinds of electrolysers are fed with liquid water, achieving efficiencies of 75-80 and 90 % respectively (versus high heating value, HHV). Within these plants, hydrogen is converted back to electricity through PEM Fuel cell or internal engines. However, several studies have shown great advantages of high temperature steam electrolysis with Solid-Oxide electrolysis cells (SOEC) over liquid water electrolysis, which operates in the range of 600 to 1000 ºC. From a thermodynamic point of view, hydrogen split reaction can be described by the Gibbs function,

$$\Delta G = \Delta H - T \cdot \Delta S \tag{1}$$

where ΔH is the overall energy needed, ΔG is the electrical energy and $T \cdot \Delta S$ is direct heat. As can be seen Fig. 1, electrical requirement decreases and heat energy demand increases with increasing temperature. Even though total energy demand increases, the decrease in electrical energy demand is more noticeable. From the kinetic point of view, high temperature helps to promote electrode activity and reduce cell overvoltage. It means that power density can be increased, reducing the size of the electrolyser for a given production. Additionally, lower cell overvoltage can be translated to lower energy losses, thus more electric efficient process [11]. And finally, Solid-Oxide systems are able to work either as electrolyser (SOEC) or as fuel cell (SOFC), reducing the number of units and its auxiliary elements of a P2G plant. All these advantages projects lower generation cost than with the current technology [12], [13].