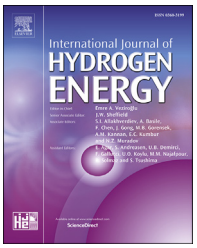
INTERNATIONAL JOURNAL OF HYDROGEN ENERGY XXX (2017) 1–10

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/he



Development of a solar powered hydrogen fueling station in smart cities applications☆

*Giorgio Dispenza**, *Francesco Sergi*, *Giuseppe Napoli*, *Nico Randazzo*, *Samuele Di Novo*, *Salvatore Micari*, *Vincenzo Antonucci*, *Laura Andaloro*

National Research Council of Italy, Institute of Advanced Energy Technologies, Via Salita S. Lucia Sopra Contesse, 5, 98126, Messina, Italy

ARTICLE INFO

Article history:
Received 9 May 2017
Received in revised form
19 June 2017
Accepted 7 July 2017
Available online xxx

Keywords:
Hydrogen fueling station
Hydrogen
Fuel cell
Smart city

ABSTRACT

This paper reports main criteria for design, realization and validation of a solar-powered hydrogen fueling station in a smart city application relevant to an on-site hydrogen production plant. The program has been developed by CNR-ITAE together with other industrial partners in the framework of the Italian research project called i-NEXT (innovation for greeN Energy and eXchange in Transportation). The i-NEXT hydrogen production plant is located in the Municipality of Capo d'Orlando, Sicily, it is fed by a microgrid able to receive energy from solar radiation by a 100 kW rooftop photovoltaic plant and connected with a battery energy storage of 300 kWh (composed by 16 sodium nickel chloride high temperature batteries). The plant is able to deliver hydrogen and electricity for an electric and hydrogen vehicles fleet. The hydrogen fueling station includes four subsystems: a hydrogen production system by electrolysis, a compression system, a high-pressure storage system and a hydrogen dispenser for automotive applications. It is able to generate in the hydrogen production subsystem through an alkaline electrolyzer of 30 kWh: 6.64 Nm^3/h of H_2 with a gas purity of 99.995% (O_2 < 5 ppm and dew point < −60 °C). The compression subsystem has a three stage compressor with a rated gas flow rate of 5,2 Nm^3/h and a delivery pressure of 360 bar. The compressed H_2 gas is stored in a high-pressure tanks of 350 L capacity allowing, in this way, a supply through a dispenser system of two automotive's tanks of 150 L @ 350 bar in less than 30 min. This paper reports the design and the development results coming from a first test campaign.

Introduction

The transport sector remains a major source of air pollutants, it was responsible for about 30% of world energy-related greenhouse gases (GHG) emissions and for around a half of all energy-related nitrogen oxide emissions (56 Mt in 2015) [1]. Hydrogen has the potential to aid in increasing the use of renewables energy resources and to contain greenhouse gases emissions by acting as an energy carrier. Then,

Nomenclature and abbreviations: GHG, Green House Gases; FCEV, Fuel Cell Electric Vehicle; FCHEV, Fuel Cell Hybrid Electric Vehicle; BEV, Battery Electric Vehicle; BESS, Battery Energy Storage System; SOC, State of charge; DOD, Depth of discharge; VPN, Virtual Private Network; PLC, Programmable Logic Controller; AC, Alternating Current; DC, Direct Current; HPPS, Hydrogen Production and Purification Section; HCS, Hydrogen Compression Section; HSS, Hydrogen Storage Section; HRS, Hydrogen Refueling Section.

☆ E-MRS 2016 - Advanced Materials for Fuel Cells and Electrolyzers Warsaw University of technology - Poland 18-22 September 2016.

* *Corresponding author.*
E-mail address: giorgio.dispenza@itae.cnr.it (G. Dispenza).

http://dx.doi.org/10.1016/j.ijhydene.2017.07.047

European environmental policy is addressed toward the development of low emissions vehicles characterized by the installation of clean innovative devices as Fuel Cell power trains [2,3]. In order to support the deployment of fuel cell electric vehicles (FCEV) fed by hydrogen, it is important to develop a refueling network and to assess the performance, the consumption and the operation of onsite hydrogen production and fueling stations [4–7]. Within an Italian research project "i-NEXT" (innovation for greeN Energy and eXchange in Transportation, sponsored by PONREC - Ministry of Education, University and Research [8]), CNR-ITAE, together with other industrial partners, has developed the first Italian hydrogen production and fueling plant. Actually in Europe there are 49 hydrogen refueling stations in operation [9], but few of them exploit renewable energies. This hydrogen production and fueling plant is connected to a microgrid and it is able to receive, as input, the energy coming from solar radiation and to deliver, as output, hydrogen and electricity for refueling of an electric and hydrogen vehicles fleet. The i-NEXT hydrogen plant is located in the Municipality of Capo d'Orlando - Sicily, the hydrogen is produced by an electrolyzer connected with hydrogen storage facilities. The peculiar characteristics of this plant is that, since it is connected to a photovoltaic plant and a Battery Energy Storage System (BESS), the electrolyzer is able to generate hydrogen regardless, too, of the presence of the renewable source or refueling demand, also the entire energy system is grid connected which could facilitate their operation in electricity markets. This paper shows the design and the development coming from a first test campaign.

Design of the solar-powered hydrogen refueling station

The plant is the first Italian solar-powered hydrogen fueling station and it was designed in order to be directly supplied by a solar renewable energy source. Solar plant and daily hydrogen production were designed for a daily fueling of one hybrid electric fuel cell/batteries minibus, one electric minivan and two electric bicycles assisted by fuel cell power system (vehicles was developed by CNR ITAE as part of the iNext project [8]).

Design of the hydrogen refueling station

Input data for the design of the hydrogen fueling station has been mainly: daily autonomy of iNext bus used for the transportation of tourists in Capo d'Orlando municipality and therefore the amount of hydrogen for daily production. The iNext bus is a prototype of hybrid electric fuel cell/batteries having an electric drive engine with a rated power of 40 kW and a capacity of 16 passengers. Fig. 1 shows a photo of the hybrid minibus and the relevant datasheet is reported in Table 1. The selected powertrain configuration of range extender allows reducing costs, weight and recharging time of batteries and it allows to increase the range in comparison to an equivalent electric vehicle. The bus is equipped with two high-pressure tanks of 150 L each, reinforced in carbon fiber, with a total amount of about 7 kg of hydrogen at 350 bar. This volume enables the vehicle to have a greater autonomy of 240 km in FCHEV mode. The average distance covered by iNext bus is of 200 km/day, so, in this way, it needs a daily refueling only. Therefore, the production of hydrogen in the refueling station is sized for 8.5 kg/day in order to ensure the daily utilization of the vehicle.

The hydrogen refueling station was designed starting from this input data (needed hydrogen for day) tacking on account the availability of commercial components to minimize overall capital costs. The plant mainly includes four modules: a hydrogen production and purification module (HPPS), a hydrogen compression module (HCS), a hydrogen storage facility (HSS) and a hydrogen refueling facility (HRS). The P&ID is reported in Fig. 2.

In the first section HPPS, hydrogen is produced at 9 bar starting from deionized water by an alkaline electrolyzer and subsequently, after deoxidation and drying process, it is analyzed trough an electrochemical cell oxygen analyzer and then it is stored in a low pressure buffer tank (9 bar). In the second section HCS, the hydrogen is suctioned from low pressure buffer and through a three intercooled stage compressor it is compressed up to 360 bar and it is stored in an high pressure buffer tank. The bus refueling takes place by means of an automatic hydrogen dispenser in the HRS section. The HSS module includes a storage system of 48 vertical cylinders of 50 L at 200 bar for emergency backup of hydrogen in case of scheduled maintenance or fault of the HPPS or HCS modules.

The production, compression and refueling of hydrogen, including all operating parameters, are managed through automatic logic from the PLC control panel. The entire hydrogen fueling station is designed to be placed in three 20 ft standard ISO containers (Dimension L × P × H: 6100 mm × 2500 mm × 2600 mm) and an external view is shown in Fig. 3. In order to be compliant with the safety standards, a gas-tight wall separates the electrical system and the compressor/storage compartments. All controls and electrical power switch gear are located in the electronics compartment. A pressure discharge vent is located in the roof of the gas compartment. The refueling station is continuous monitored for leakage also in stand-by mode, hydrogen gas detection and smoke detection devices are located inside containers and an automatic emergency shutdown (ESD) shuts down station operation in case of emergency [10].

All four sections comply with the regulations:

- Directive PED 97/23/EC concerning pressure equipment [11];
- Directive ATEX 94/9/EC concerning a potentially explosive atmosphere exists when a mixture of air gases, vapours, mists, or dusts combine in a way that can ignite under certain operating conditions [12];
- Directive 98/37/EC concerning the machinery [13];
- Directive CEI EN 60079-14 concerning the electrical installations design, selection and erection in explosive atmospheres [14];
- Italian Legislative Decree 31/08/2006 concerning the technical regulation of fire prevention for the design, construction and operation of automotive hydrogen refueling stations [15];

Please cite this article in press as: Dispenza G, et al., Development of a solar powered hydrogen fueling station in smart cities applications, International Journal of Hydrogen Energy (2017), http://dx.doi.org/10.1016/j.ijhydene.2017.07.047