INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 42 (2017) 20979–20993

Available online at www.sciencedirect.com

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

From solar to hydrogen: Preliminary experimental investigation on a small scale facility

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ARTICLE INFO

Article history:
Received 11 April 2017
Received in revised form
16 June 2017
Accepted 18 June 2017
Available online 24 July 2017

Keywords:
Photovoltaic
Hydrogen
Battery
Experimental setup
Stand-alone power system

ABSTRACT

Issues of exhaustible natural resources, fluctuating fossil fuel prices and improvements in electric power systems motivated governments to behave positively toward the development of distributed generation. In addition, progresses in small size generation technologies and storage systems give rise to a significant diffusion in microgrids, working together with conventional power grid. Indeed, in the next future, domestic microgrids are expected to play a fundamental role in electric power networks, driving both the academic and industrial research interests in developing high efficient and reliable conversion and storage technologies.

In this context, this study presents a feasible configuration of a solar-hydrogen integrated microgrid and documents the procedure to characterize the overall efficiency of a laboratory scale test facility. Experimental results highlight that the most significant inefficiencies in the solar to hydrogen conversion process are mainly attributed to the solar to electrical energy conversion process, being responsible for about 89% of losses. The overall laboratory scale solar to hydrogen chain can reach conversion efficiency up to 5.3%.

Introduction

The rational exploitation of renewable sources, the improvement in conversion efficiencies, the reduction of wasted energy and the minimization of pollutant emissions are the crucial purposes of any energy policy, whether applied at local, national or global level [1]. Distributed generation (DG) is one of the key strategies for achieving these goals [2]. DG plays a fundamental role also in rural areas, where power deliver over long distance is difficult and uneconomical [3]. In those areas, energy supply requirements must be guarantee taking advantage from stand-alone hybrid systems typically dependent on renewable sources [4]. As a consequence, a key role in the DG network is played by renewables and, in particular, by the non-programmable sources such as solar and wind [5,6]. As known, the characteristics of non-programmable sources are adverse to the diffusion of renewable energy; in particular, intermittency presents a great challenge in energy generation and load balance maintenance to ensure power network stability and reliability [7–10]. Great efforts have been made in searching for viable solutions, including Electrical Energy Storage (EES), load shifting through demand management, interconnection with external grids, etc. Among all, EES has been recognized as one

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http://dx.doi.org/10.1016/j.ijhydene.2017.06.141

Nomenclature

Acronyms

AC	Alternating Current
DC	Direct Current
DG	Distributed Generation
EES	Electrical Energy Storage
ER	Voltage
FC	Fuel Cell
HG	Hydrogen Generator
IR	Current
LR	Water Quality
MPP	Maximum Power Point
MPPT	Maximum Power Point Tracking
NOC	Nominal Operating Condition
PEM	Proton Exchange Membrane
PV	Photovoltaic
PWM	Pulse Width Modulation
QR	Mass Flow Rate
RR	Solar Radiation
SE	Solar Emulator
SCR	Solar Charge Regulator
SOC	State Of Charge
STC	Standard Condition
TR	Temperature

Greek symbols

η	Efficiency [–]

Symbols

E	Energy [Wh]
HHV	Higher Heating Value [kJ/kg]
I	Current [A]
IR	Solar Irradiance [W/m^2]
m	mass flow rate [kg/s]
P	Power [W]
S	Surface [m^2]
V	Voltage [V]

Subscripts

aux	Auxiliary
B	batteries
H_2	Hydrogen
in	Inlet
INV	Inverter
OC	Open Circuit
Out	Outlet
Net	Network
SC	Short Circuit

of the most promising solution with a huge potential in meeting renewable challenges [11,12]. In fact, in order to match final user needs with renewable sources energy generation, the presence of storage devices is of fundamental importance. According to generation technology and users needs, different EES systems can be used to store energy in the most efficient way. A deep review on EES state-of-art can be found in Refs. [13–20]. For small/micro size applications, among all EES devices, batteries are the most diffused solutions. Batteries are suitable for different applications, such as power quality, energy management, riding through power and transportation systems [19]. At present, research and development on batteries are mainly focused on: (i) new materials to improve performance, (ii) extending the useful life by increasing the maximum cycling rates, (iii) improving charging/discharging capabilities. Batteries integration, as electrical storage devices, with renewable sources (solar and/or wind) is fundamental for application in microgrids.

Several projects and research activities are currently focused on chemical storage and, in particular on the investigation of affordable approaches to extract large amounts of hydrogen from water by using renewable, non-programmable sources. Generated hydrogen through water electrolysis can be stored in canisters for later use in fuel cell for electricity and heat generation, thus resulting in combined heat and power technologies [19].

In this context and to perform experimental surveys on this topic, a new laboratory has been set-up by the Energy and the Environment Interdepartmental Centre for Industrial Research, CIRI-EA, of the University of Bologna at Ravenna Technopole. The "*microgrid and storage*" laboratory test facility is within the scope of the High Technology network of Emilia-Romagna. Present and future research activities are expected to define optimal operations and control strategies to exploit small scale renewable sources in a rational and effective way, also tanks to the use of different storage devices. The laboratory of integrated microgrid consists of solar photovoltaic panels (PV) for the exploitation of the renewable non-programmable source, batteries and a hydrogen generator (HG) as storage technologies, power electronics including inverter and converter, a solar charge regulation unit (SCR) and electronic load emulators, both direct (DC) and alternate current (AC), as users. The integrated microgrid is intended to maximize the hydrogen generation starting from a renewable source through the use of batteries to compensate for solar over/under-production.

Renewable and storage technologies for micro-size distributed generation: state of the art

The literature survey on this subject mainly accounts for mathematical and semi-empirical models on integrated systems, mostly focused on sizing optimization methods and management strategies, examples can be found in Refs. [21–29]. More in details, Castañeda et al. [21] presented a sizing method and different control strategies for the energy management of a stand-alone hybrid system based on photovoltaic solar panels, hydrogen subsystem and battery, dynamic modelled in the Simulink environment. Three different control strategies were applied, based on technical-economic aspects. Study results highlighted that the hybrid system assures reliable electricity supply for the stand-alone application. However, although the configuration was found technically feasible, from the economic point of view was proven as not competitive. Ipsakisa et al. [22] developed efficient power management strategies for a stand-alone hybrid system, currently in operation in Greece, made up of a photovoltaic array, a wind generators and an electrolyzer to store renewable surplus energy via hydrogen production. Simulation results, under specific weather conditions, showed