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Experimental Investigation On A Solar/Hydrogen-Based Microgrid

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Abstract

In this paper an experimental investigation on the performance of an integrated microgrid, installed at the laboratory of the University of Bologna, is presented. The integrated microgrid is made up of two photovoltaic solar panels, two batteries as electricity storage device, a hydrogen generator and an electronic load emulator. The direct current generated by the solar modules charges the batteries by means of a load regulator unit. The power electronics, including an inverter and a DC converter, provide the user with 12 V DC and 230 V AC to feed the electronic load and hydrogen generator, respectively.
The aim of this experimental activity is to investigate batteries charging/discharging process and, as a consequence, to quantify batteries roundtrip efficiency value. Experimental trend of voltage, current and power input/output from batteries are observed during charging/discharging operation. Results of the experimental activity show that during the charging process, the voltage from the solar array tapers according to the batteries conditions and recharging needs, thus increasing the charge acceptance of the battery. Once batteries are about to reach full charged condition, the controller starts to hold constant voltage and reduce the charging current to avoid overcharging. Taking advantage of experimental activity results, average value of batteries roundtrip efficiency is determined.

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Keywords: microgrid; experimental setup; solar, hydrogen; storage; battery.

1. Introduction

Distributed generation (DG) is significantly growing in the last decade. Improvements in small size generation technologies and storage systems make DG settled as active networks, working together with conventional power grids. In addition, issues of exhaustible natural resources, fluctuating fossil fuel prices and uncertainty of electricity supply push governments to behave positive toward the development of integrated microgrids, which are supposed to play a fundamental role in the next future [1, 2]. Preliminary investigations on abovementioned context have been carried out by Authors in [3-5] dealing with optimal size and performance analysis of grid-independent hybrid solutions for residential application. In this context, a new laboratory has been designed and 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 testing facilities are within the scope of the High Technology network of Emilia-Romagna. The carried out research activities, in the field of renewable energy exploitation and electricity storage, are, at the present, aimed at characterizing the overall solar-hydrogen generation chain efficiency on the basis of system experimental behavior.

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First step, presented in this study, of a planned comprehensive research activity, is the investigation of batteries charging/discharging process and the estimation of roundtrip average efficiency value.

2. Microgrid description

The experimental test bench, presented in Fig. 1, consists of an integrated microgrid connecting a renewable power source with an energy storage device, to supply loads. More in detail, the microgrid accommodates the following components: two solar modules, a power management cabinet including a solar charge regulator unit, two block batteries, a DC/DC converter and a DC/AC inverter, a hydrogen generator, three metal hydride storage canisters and, finally, a DC electronic load emulator. The solar arrays, the power management cabinet and the hydrogen generator are from Heliocentris mobile unit for solar hydrogen production [6]. The integrated microgrid is intended to maximize the hydrogen generation starting from a renewable source through the use of batteries, working as electricity storage device, compensating for solar over/under-production. In Table 1 main technical data of integrated microgrid installed components are summarized. Within the next future the migrogrid will be equipped with a solar emulator and an electronic AC load (dotted components in Fig. 1). Fig. 1 shows the schematics of the electric microgrid where measuring sensors are installed. In order to collect data of microgrid operation the test bench is endowed with sensors for current (IR), voltage (ER), temperature (TR), solar radiation (RR) , mass flow rate (QR) and water quality (LR).

Table 1: technical data of microgrid main components [6]

System	
Max. input current, photovoltaics	30 A
System voltage, photovoltaics	24 V DC
Max output current 12 V DC	2 A
Max. continuous output 230 V AC	700 W
Momentary peak load	1050 W (10 sec)
Output voltage frequency	230 V, 50/60 Hz, true sinus
Solar Modules (each)	
Type	Polycrystalline
System voltage	24 V DC
MPP output	220 W
Efficiency	15% @ AM 1.5
Short circuit current	8.62 A
MPP voltage	27.54 V

Batteries (each)	
Type	Solar lead-acid battery
System voltage	12 V DC
Capacity	55 Ah
Hydrogen generator	
Type	Proton Exchange Membrane
Production capacity	30sl/h @10.7 bar
Hydrogen purity	6.0 (99.999%)
Input voltage	120 VAC /50- 60 Hz
Max. consumption	300 VA
Electronic DC Load emulator	
Input Voltage range	0-360 V
Input power range	0-300 W
Input current range	0-30 A

Solar energy is converted into electrical energy with the solar photovoltaic modules (PV) connected in parallel and located on movable racks with an adjustable angle so that they can be positioned facing various directions. Each of the solar modules delivers up to 220 W as maximum power output at standard condition (AM 1.5). A sensor kit is connected to the PV array recording ambient (TR1) and module temperature (TR2) and solar radiation (RR). The direct current generated by the solar modules charges the batteries by means of the solar charge regulator unit: in fact, charging a battery through a PV module without a regulation device is to be avoided because it can damage battery itself and shortening its life cycle. In practice, a DC/DC converter is necessary to regulate and provide suitable charging voltage/current according to the battery specifications. Several type of charge controller units can be used; devices can be divided into two main categories: Pulse Width Modulation (PWM) and Maximum Power Point Tracking (MPPT) controllers. While units belonging to first category work regulating the current and voltage from PV panels depending on battery state of charge (SOC); controllers of the second group perform battery charging keeping PV panels close to maximum power point condition for given incident solar radiation and weather conditions. The controller unit currently installed at the laboratory is a PR 3030 using the PWM method [7, 8]. A PWM controller is less expensive compared to a MPPT and represents a good trade-off choice for small systems. Moreover, performance advantage of MPPT controllers is significant, in particular, when the solar cell temperature is low (below 45 °C), or very high (above 75 °C), or when irradiance is very low [9]. In detail, once charge takes place, the current is controlled via PWM shunting of the module input. Depending on the batteries SOC, the regulator adjusts charging rates to allow charging operation closer to the batteries maximum capacity as well as monitors batteries temperature to prevent overheating. The two block batteries, Banner Stand by Bull Block 55Ah/12V, work in series to store the renewable energy coming from PV arrays. The DC/DC converter, Meanwell SD-25B-12, feeds the electronic load converting 24 DC voltage from batteries down to 12 V DC. The DC/AC Inverter feeding the Hydrogen Generator (HG) is a Meanwell TS-700-224B generating 230 V AC voltage for the HG unit. The Hydrogen Generator, HG 30, enables the