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Fuel cell based Hybrid Renewable Energy Systems for off-grid telecom stations: Data analysis from on field demonstration tests ☆

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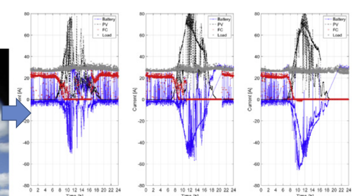
HIGHLIGHTS

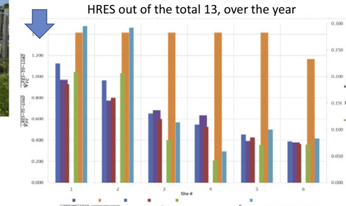
- Fuel cell based Hybrid Renewable Systems are presented for Telecom stations.
- Systems include PV, batteries, Fuel Cells and electrolyzers.
- Results from the field are presented for several telecom off-grid sites.
- Results refer to a period of observation of one full year (in 2015).
- The performances of the systems are compared through proper indicators.

GRAPHICAL ABSTRACT

Annual testing of 13 Hybrid Renewable Energy Systems (HRES) on the field for off-grid telecom applications coupled to real Radio Base Stations (RBS) in service



Measurements of power plots over time on the field for 6 HRES out of the total 13, over the year



Calculation of synthetic performance parameters describing the performance of the 6 HRES over the year

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ABSTRACT

The results of a wide demonstration test of Off-Grid Radio Base Stations powered with fuel cells and locally available renewable energy sources are presented. The experimental activity has been conducted as part of the FCPoweredRBS project to assess and verify the potential of hydrogen and fuel cells as power and energy sources for the telecom market. For this application, Fuel Cells have been integrated as a programmable power generator with a photovoltaic system and an energy storage system. Both electrochemical batteries and hydrogen produced locally with an electrolyzer have been tested as energy storage solutions. Data collected for a full year have been used to assess the potential of the systems proposed in comparison with diesel generators which are the standard solution for such applications. Results show that the hybrid renewable energy solution may be competitive in terms of energy efficiency and minimum consumption of fossil fuel consumption. Proper sizing and control strategy optimization are key aspects to this aim. Despite the use of FC technology and the integration of many different components, field tests have shown an acceptable level of stability and reliability.

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Nomenclature

Acronyms

DC	Direct Current
EB	Electrochemical Batteries
FC	Fuel Cell
FES	Fossil Energy Sources
HRES	Hybrid Renewable Energy Systems
LHV	Lower Heating Value
MPPT	Maximum Power Point Tracking
PEM	Polymer Electrolyte Membrane
PV	PhotoVoltaic
RBS	Radio Base Station
RES	Renewable Energy Sources
SOC	State Of Charge
TCO	Total Cost of Ownership

Symbols

E	energy [J]
H_2	hydrogen
I_{size}	size index [ ]
LHV	Lower Heating Value [J/kg]
M	mass [kg]
t	time [s]
T	period [s]

Greek symbols

η	efficiency [ ]
$\bar{\eta}$	average efficiency [ ]
η^*	reference efficiency
ψ	performance coefficient [ ]

Subscripts and superscripts

elec	electrolyzer
excess	excess (referred to excess power)
in	inlet
out	outlet
sys	system
EB	battery
FC	fuel cell
PV	photovoltaic

1. Introduction

The rapidly growing telecommunication market in many different countries requires an increasing number of Radio Base Stations (RBS) as an alternative to telephone cable networks. The use of off-grid RBS is increasing significantly, in emerging markets, where 3G and 4G networks are spreading as preferred solutions for green-field network development: recent studies [1,2] estimated that by 2020 there could be up to 400,000 off-grid RBS operating on renewable power in remote parts of the developing world. In fact, for their nature, RBSs are often located in remote areas, where grid power may not be available and energy should be produced locally by means of low efficiency and emission-intensive power supply solutions such as Diesel gensets [2]. Alternative power supply solutions based on the use of renewable sources coupled with electric energy storage and some form of programmable energy production are becoming an attractive and feasible solution to guarantee reliable, efficient and clean energy production to remote RBS. For this application, the use of hydrogen and fuel cells for chemical energy storage and programmable and efficient energy production has been identified as a potential competitive solution to standard diesel generators [3,4]. The integration of renewable energy sources as Photovoltaic (PV) and wind with electric batteries and hydrogen in a Hybrid Renewable Energy Systems (HRES) represents a very effective energy generation solution for remote application [5,6]. In fact, HRES integrating hydrogen storage and fuel cells as programmable sources are attractive as they may operate unattended for longer periods due to a typically high conversion efficiency (i.e. low fuel consumption), cheap maintenance costs [7], low noise and fastr/easy starting-up features [8], and heat management high potential at low temperature ambient conditions [9]. They may further satisfy the RBS energy requirement with very low CO_2 emissions in line with existing and future greenhouse emission limits.

Telecom specifications on energy production quality are very demanding (24 h/7 day continuous supply, high availability, long autonomy without attendance) and under these condition HRES integrating electrochemical energy storage with local hydrogen production and storage represent an effective solution if compared to battery or hydrogen only systems [10,11]. In fact, the integrated use of the Electrochemical Batteries (EB) for short term storage and hydrogen locally produced by electrolysis for medium term and potentially seasonal storage, allows for a more effective utilization of local renewable energy sources not penalizing excessively the EB life cycle [12,13]. HRES effectiveness however depends on proper sizing of the different components as a function of the load and on the design of the control strategy, that requires optimization [10]. Power requirements for a RBS are different for every site, as requests may depend on coverage capability, energy consumption, technology and costs [14] as well as on weather conditions. Lead acid batteries have been the preferred electrical storage choice so far for HRES [8] but recent developments in terms of costs, and performances for Li-ion and NiCd batteries are going to change the scenario. Moreover, systems may be very different in terms of design optimization and control strategies [15–18]. The power ratio of different components is site dependent and may be very variable. This also applies to local solar radiation profile, load consumption profile and battery technology and durability issues [19]. Moreover, system performances in terms of efficiency [8] and Total Cost of Ownership (TCO) may be highly variable and would definitely depend on the control strategy, or on the durability target of expensive components such as battery or fuel cell based sub-systems [8,20,21]. In fact, HRES in the 1 kW power size are typically rather simple [22], using hierarchically the cheaper available energies on board: first renewables, then stored, then fuel cells, the only programmable power source, first fed by locally converted (through electrolyzer) H_2 at 30 bar, and then by compressed H_2 brought on site in bundles [10]. However, there are a number of issues besides the static optimization of system design and control strategy, which are related to the effect of sudden variations of radiation profiles during field operation and their influence on the standby/switch-off logic for electrolyzers and fuel cells as well as batteries lifetime [23]. Specific system settings, such as the bus voltage, need to be properly selected as control parameters.

In this scenario, the EU funded demonstration project FCpoweredRBS "Demonstration Project for Power Supply to Telecom Stations through FC technology" [9,24] aims at proving the

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