Renewable Energy 93 (2016) 14–26

Contents lists available at ScienceDirect

Renewable Energy

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

Energy sovereignty in Italian inner areas: Off-grid renewable solutions for isolated systems and rural buildings

Maria Elena Menconi [a,*], Stefano dell'Anna [a], Angelo Scarlato [b,1], David Grohmann [a]

[a] University of Perugia, Department of Agriculture, Food and Environmental Sciences, via Borgo XX Giugno, 74 06100, Perugia, Italy
[b] FdS Srl, La Fabbrica Del Sole, Italy

ARTICLE INFO

Article history:
Received 9 July 2015
Received in revised form
7 January 2016
Accepted 10 February 2016
Available online 27 February 2016

Keywords:
Off grid energy system
Photovoltaic system
Chemical energy storage
Rural buildings
Scenario analysis
Energy autonomy

ABSTRACT

This paper deals with a compact system developed to assure energy independence to buildings located in inner rural areas: the Off-Grid Box. This system features a combination of techniques that assure the use of several renewable energy sources, their storage and the rationalization of consumption.

This research studies the base model of the Off-Grid Box, which entails the presence of photovoltaic panels as the energy capture system.

The aim of this research is to evaluate the opportunity of realizing a system to ensure energy autonomy of rural residential buildings. To achieve energy independence, for an isolated dwelling, this paper assesses the optimal storage systems that may be combined with a photovoltaic system. To this end, an Off-Grid Box has been installed in a residential unit in central Italy. Starting from the real case, two alternative energy storage scenarios were constructed. The results can be applied to a variety of geographical settings and prove the feasibility and strategic importance of total off-grid systems for individual residential units, when they are designed in integrated terms in the area to implement small-scale-smart-grids. In rural areas, these grids should also cater for small farming businesses that feature a different consumption distribution compared to dwellings.

1. Introduction

The topic of energy planning and streamlining energy use has a strategic importance at this time. The European Union has set itself certain goals to achieve by 2020: meeting 20% of its energy requirements from renewable sources and, with respect to 1990, a 20% reduction in greenhouse gas emissions and a 20% increase in energy efficiency [1]. To date, the debate is open and the political activity at the EU level is lively and proactive [2]. The goal set at the international level is to turn buildings from energy-consuming systems into active systems. The passive house concept has been replaced by that of the nearly zero-energy building, defined by the European Union as “building that has a very high energy performance […]. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on site or nearby” [3]. Jointly with these aspects it is of extraordinary importance to “activate”, from the energy point of view, buildings and production processes able to assure energy security regardless of the social-economic setting of reference [4].

1.1. Inner areas and energy sovereignty

Inner areas are territories characterized by a not adequate offer of/access to essential services to assure a certain level of citizenship among population and substantially far from large and medium-sized urban centers able to supply adequate services.

In the 2014–2020 European strategy, inner areas are the subject of specific integrated projects aimed at development and enhancement of local communities [5,6]. Inner areas are considered strategically relevant to foster a more sustainable and inclusive national growth. From the energy point of view these areas are characterized by low consumption, which, however, is difficult to satisfy. In fact, even when the consumption demand is reached by the existing networks, it involves high costs and multiple operating issues. In these settings the concept of energy sovereignty is

* Corresponding author.
E-mail addresses: mariaelena.menconi@unipg.it (M.E. Menconi), stefano.dellanna@studenti.unipg.it (S. dell'Anna), angelo.scarlato@lafabbricadelsole.it (A. Scarlato), david.grohmann@unipg.it (D. Grohmann).
[1] www.lafabbricadelsole.it.

http://dx.doi.org/10.1016/j.renene.2016.02.034
0960-1481/© 2016 Elsevier Ltd. All rights reserved.

especially significant, linked to the establishment of development models, accepted and embraced by the local communities, based on the sustainable and long-lasting use of natural resources [7,8].

The concept of energy sovereignty is a part of the interesting alternative vision of the green economy. This concept recognises energy as a human right. It also seek to return the control of energy users, rather than remote corporations that seek to profit from regardless of its impact on consumers or how it is generated [9,10].

The establishment of energy sovereignty is strongly connected to the development of renewable energies, which, by their own nature, are spread throughout the region. Table 1 shows the significant development of renewable energies at the EU level since 2000. This development is connected to a widespread increase in energy consumption that has also involved growing energy production from coal and gas (+25 and +23% respectively). Despite the positive performance of renewable energies recorded globally in the last few years, we can state that the average energy produced is still definable as "dirty", as it was twenty years ago. According to the International Energy Agency the Energy Sector Carbon Intensity Index (carbon intensity indicator per unit of energy produced) has decreased by less than 1% since 1990. The cause of all this lies in the fact that coal continues to be the dominant energy source, within a picture of continuously and significantly increasing energy consumption (Table 1) [11].

In the case of Italy, the increase in the use of renewable energies reflects the European trend. This increase has entailed local overloads to the existing energy distribution grids, which should be redesigned and upgraded, also in view of the energy storage possibilities afforded by net metering [12].

That observation reinforces the importance of reasoning in terms of energy sovereignty, imagining a widespread energy system, unfettered by the presence of traditional distribution grids. Research is focusing on the integration of various energy sources to design off-grid systems suited to the regions where they are located [13–17].

1.2. Energy storage systems

In Italy, renewable energy sources are divided into programmable and non-programmable sources. The first category includes reservoir and basin hydroelectric production units, municipal solid waste, biomass, assimilated production units using fossil fuels, process fuels or residues; while the second includes flowing hydroelectric production units, wind, geothermal, photovoltaic (PV) and solar in general and biogas [18].

For the non-programmable renewable energy sources, the challenge of energy independence is identifying the optimal storage systems that can guarantee useful energy supplies in space and time, finding solutions that meet the high variability of production profiles at hourly, daily and seasonal times and adapting to the various energy demand profiles.

In Italy, PV is the non-programmable renewable energy production system that has been most extensively developed over the last few years thanks to the government's incentive policy. There is an open debate in Italy on regulating the use of energy storage systems in new plants and in introducing them to existing plants [19].

At the planning scale, research is focusing on analysing the technical and economic feasibility of smart grids, in order to assess their optimal organization and effectiveness within a framework of energy sovereignty [20–23].

At the individual plant level, research has focused on identifying the best energy carriers and on the integration of renewable energy sources. The electricity storage systems are classified according to the technology used in electrical (super-capacitor, superconductive magnetic coil), mechanical (pumped hydropower, compressed air energy storage system, flywheels), thermal (thermoelectric storage) and chemical (lithium-ion battery, lead-acid battery, high temperature batteries, flow batteries, hydrogen storage, natural gas storage system) [20,24].

This presentation draws a comparison between Valve-Regulated Lead-Acid batteries, gel cell type and Lithium-Ion batteries, because they represent chemical storage systems widely present on the market and they are potentially suitable for applications in small residential and production units. Moreover, these type of batteries can be considered low cost compared to potentially more efficient energy carriers, such as fuel cells.

The main advantage of lead-acid batteries is their low cost: a large battery (e.g. 70 Ah) is relatively cheap, when compared with others with the same chemical operation principle. Other positive aspects concern their long life and reliability at low temperatures. The negative aspects include the lower energy intensity compared to other known chemical batteries, losses connected to mechanical stresses, the sulfation phenomenon resulting in their deterioration when subject to prolonged discharges, the heaviness and toxicity of lead and the high weight and volume that hardly favor compact applications [24,25].

Lithium-Ion batteries offer very high energy density (7 g of metal produce up to one mole of electrons) and do not feature the memory effect. The negative aspects include high costs, flammability of the solvent (there is an explosion hazard in non optimal conditions) and marked unsustainability of the lithium production chain [24,26]. Further, scaling up the lithium battery technology for different micro-applications is still problematic [27].

Fig. 1 shows various storage technologies and their development perspectives with a 2030 horizon [28–30].

The main challenge consists of assessing the scalability and integrability of the various non-programmable renewable sources and the various storage systems.

With regards to studies related to integrating several energy sources, Sen et al. [31] simulate the combination of various sources (small-scale hydropower, PV, wind turbines and bio-diesel generators) with the aim of assuring a community's energy security summing its various requirements (residential, institutional, retail and agricultural sectors); Thompson et al. [32] prove the greater economic and environmental efficiency of solar and wind energy compared to the energy produced with fossil fuels in a total off-grid situation. Shaahid et al. [33] prove the positive integration between a PV system and a diesel plant in an inner area through a technical-economic assessment. Another interesting study is that by Kanase-Patil et al. [34], which shows the possibility of meeting the energy requirements of an isolated area by implementing four different

Table 1
EU 27: available power from 2000 to 2012. Source International Energy Agency.

	2000		2012	
	GW	%	GW	%
coal	159.48	28	227.88	25
nuclear	126.47	22	120.26	13
gas	89.90	16	214.99	23
fuel oil	66.52	12	50.55	6
hydroelectric	110.07	19	126.35	14
photovoltaics	0.13	n.d.	68.99	7
wind	12.89	2	106.04	11
biomass	2.79	1	7.31	1
concentrating solar	0.0	0	1.89	0
renewable municipal waste	0.0	0	3.85	0
waves and tides	0.0	0	0.26	0
total EU-27	568.25	100	928.37	100
of which renewable energy	125.87	22	314.69	34