Applied Energy 155 (2015) 308–314

Contents lists available at ScienceDirect

Applied Energy

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

Optimization of a hybrid renewable system for high feasibility application in non-connected zones

Elías Hurtado, Elisa Peñalvo-López, Ángel Pérez-Navarro *, Carlos Vargas, David Alfonso

Instituto de Ingeniería Energética, Universidad Politécnica de Valencia, Spain

HIGHLIGHTS

- A hybrid renewable energy system has been designed, built and checked.
- It includes photovoltaic, biomass gasifier, batteries and controlled microgrid.
- We put special emphasis in the need for a high reliability of this system.
- System was checked in the laboratory and operates for long periods of time.
- Now system operates at full power with a satisfactory behavior.

ARTICLE INFO

Article history:
Received 18 December 2014
Received in revised form 8 May 2015
Accepted 29 May 2015

Keywords:
Renewable energy
Hybrid systems
Reliable supply

ABSTRACT

Renewable systems are especially suited for electricity generation in remote areas but, where high reliability of the electricity supply is required, a hybrid system including electricity storage could be the only solution to avoid the lack of feasibility in single renewable systems. In this paper a hybrid system composed by photovoltaic panels, a biomass gasifier and a battery bank is presented. The system was designed and constructed at the Distributed Energy Resources Laboratory (LabDER) in order to supply electricity to a laboratory complex in the Institut Supérieur des Techniques Appliquées, Democratic Republic of Congo (ISTA-DRC). System behavior was also tested in LabDER prior being installed and operated in the final place. Design characteristics and commissioning results are presented together with the experimental verification of the capability to fulfill the demand with very low fluctuations in the generated electricity supply.

1. Introduction

Democratic Republic of Congo (DRC) has an extraordinary potential for renewable energy generation, mainly hydro. It is estimated that the use of these resources could produce 100 GW of electrical power, 40 of them at one point, Inga [1]. Despite this, only 11% of the population in DRC has electricity access at home [2]. In addition, transport and distribution electricity network is out of date and unable to support current consumption, which results in constant power outages. In the places where electricity is essential, such as hospitals, hotels, and public buildings, the problem is circumvented by using fossil fuel generators to get some security in electricity supply. However, remote areas simply do not have electricity.

Despite it has been deeply demonstrated that electricity is necessary for the development of any community, in the case of remote and isolated communities, electricity supply is still a challenge [1]. Responding to this need, renewable energy systems (RES) may safely generate electricity for minimum demand requirements without implementing large facilities or networks by using robust systems integrated in microgrids that leverage generally abundant renewable resources in the communities in which it has to be developed the project.

As a result, hybrid renewable energy systems (HRES) are becoming more popular worldwide mainly for rural power supply. Compared to internal combustion generator systems (ICG), HREs are eco-friendly and economic, particularly when rural areas do not have easy access to fuel supply and it is brought from main cities, thus increasing the cost and environmental price of energizing [3,4]. Many previous studies on HRES are based on analyzing the specific energy needs of a geographical area and identifying the optimized energy solutions based on HRES configurations. [5] Studies carried out in rural communities demonstrate the benefits on installing HRES, as a means for reducing the dependency to fuel price fluctuations, overcoming the limitations in the electrical grid

* Corresponding author. Tel.: +34 976877270; fax: +34 976877272.
E-mail address: anavarro@iie.upv.es (Á. Pérez-Navarro).

http://dx.doi.org/10.1016/j.apenergy.2015.05.097
0306-2619/

expansion of major networks, and enhancing the use of local resources, which dońt depend on external sources and promote the sustainability of the projects [3,6,7].

Other research works are focused on implementing optimization algorithms to define the convenient HRES configuration when various objective functions are considered, such as levelized energy cost, unmet demand ratio or fuel consumption [8–10]. They are based on multi-objective and multi-criteria optimization approach, such as Pareto analysis and weighed sum or probabilistic, iterative and heuristic methods [11]. Dufo-López et al. [12] was one of the firs published research works introducing the concept of multi-criteria optimization to optimize HRES, considering the life cycle cost of the system as objective functions. Thereafter, published works have been including different objectives in the design, such as power supply reliability [8,13], pollutant emission [14], utilization of renewable energy potential [15], or the importance of identifying techno-economical parameters to represent the local context [16].

Latest studies have also incorporated into de analysis demand side management, combining HRES generation with demand response strategies, aiming for reduce the gap between the intermittency energy generation of renewables and the energy requirements. These approaches utilize demand response resources for the energy management of a micro-power system supplied by a HRES in order to guarantee the systematic exploitation of local renewable sources with a reliable power production, avoiding the expensive feedstock storage and the uncertainty of public subsidies [17].

Furthermore, this research goes a step forward in the overall evaluation of HRES, including the optimization of the design together with the experimental validation of the system operating at actual conditions. The work is organized in two main stages. On the first one, an economic optimization of the system by means of the micro-power optimization model HOMER Energy was accomplished in order to analyze the different HREs alternatives based on the local context. In this part, a feasibility analysis of the system was performed, operating as isolated system. The hybrid generation system considered was a solar plant, a biomass fixed-bed gasifier which provides syngas for operating the motor generator, a battery bank to create the grid or to serve as basic storage, and an inverter DC/AC for solar power. On the second stage of the research work, the HRES system was built and tested at LabDER prior being sent to its final destination. During the experimental validation, a programmable electrical network manager was also used in order to test the respond of the system to different load profiles. This experimental validation, together with the initial optimization process, is presented in this paper.

The project has been developed by the Institute for Energy Engineering (IIE) in collaboration with ISTA. It aims to supply electricity to a center for studying renewable energies in a two-floors building with a total area of 350 m^2. The building encloses several energy labs, computer center, classrooms, offices and power supply equipment.

HRES alternative presented in this paper corresponds to a robust electricity production systems based on the highly availability resources of solar and biomass. The project involves the use of a solar–biomass generation system to ensure a high feasible electricity supply in remote areas as well as in areas where electricity is vital.

2. Optimization of the renewable energy system configuration

The HRES system configuration was optimized for ISTA local conditions, a renewable laboratory in Kinshasha, DRC. During the process different alternatives were analyzed under constrains of being 100% renewable, so no ICG systems are considered, and a maximum annual capacity shortage of 5% allowed. ISTÁs Renewable Energy System was optimized and modeled in order to study its response to the energy requirements of the ISTA Laboratory center. The objective was to evaluate whether the optimized alternative presented for ISTA is suitable and the building energy needs are met in a reliable and sustainable manner, while analyzing the economic and environmental aspects of it. The study was conducted in several steps, beginning with the estimation of the buildinǵs demand of electricity, to continue with natural resource assessment, analysis of the technologies, evaluating the environmental and economic impact with HOMER software package developed by NREL for designing micro-power systems [18], and the experimental validation of its operation under different load profiles.

2.1. Description of the location

Solar–Biomass Generation Plant was installed at ISTA located in Kinshasa, DRC. DRC has the potential to be one of the richest countries on the African continent and a driver for African growth. Total area of DRC is 2,345,409 km^2 [19], enclosing a major river, the Congo River, and a forest area of 154,135 thousand ha. The population in 2013 was 67.51 million, with a 2.58% annual growth rate, being the capital and largest city Kinshasa. 65% of the total population is classified as rural, even though the share of urban households is growing at a fast rate. Regarding agricultural land, DRC has a total of 224,500 km^2, corresponding to 9.9% of total land area, while approximately 45% of DRC's surface area is covered by primary forest [20].

Furthermore, DRC is located in a very high solar radiation area where values ranged between 3.5 and 6 kW h/m^2. This makes installation of photovoltaic systems viable in many parts of the country, as well as the use of thermal solar systems [21].

Based on this natural potential, Kinshasa was considered a good candidate for the implementation of HRES.

2.2. Electricity demand of the ISTA laboratory building

The building energy demand, which had to be 100% covered by the ISTA HRES, has been estimated. It is composed by a computer room, a classroom, four professoŕs offices and a Renewable Energy Center enclosing a laboratory for biomass characterization and a second laboratory with the hybrid generation system. In order to accurately model the respond of the system to the energy needs, hourly demand is analyzed for the different rooms in the building. Figs. 1 and 2 show the daily energy requirements and the load profile for an average month, respectively.

Main energy needs are identified during the morning, from 7:00 until 13:00 when lunch break occurs. During the afternoon energy demand decreases, observing a stable demand of 3–5 kW from

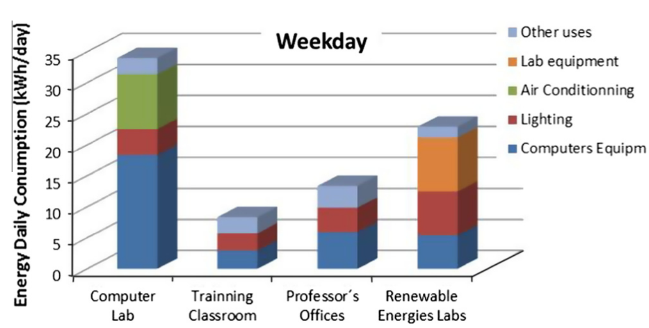

Fig. 1. Daily energy needs.