Renewable and Sustainable Energy Reviews 79 (2017) 1255–1265

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Renewable microgrid projects for autonomous small-scale electrification in Andean countries

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ARTICLE INFO

Keywords:
Rural electrification
Renewable energy
Microgrids
Andean countries
HOMER

ABSTRACT

Nowadays, 84% of the world population without access to electricity is located in rural areas of developing countries. In particular, in the Andean countries, about 10.4 million people lack of access to electricity, mainly in isolated poor regions. Considering the relevance of electricity in overcoming poverty and promoting socioeconomic development, local-regional-national governments, supported by international organizations, are making efforts to achieve full rural electrification. In this regard, renewable microgrid projects are an effective alternative where the national grid extension has limitations. The literature on the design of such projects is significant. However, when evaluating experiences, most works focus on an analysis of projects' performance from a technical and/or economical point of view. In contrast, very few literature has been reported on the comparison of such experiences from the perspective of the design process itself and how decisions are taken by project developers. In this article, five rural electrification experiences in Andean Countries (Bolivia, Ecuador, Peru and Venezuela) are reviewed, analyzing the decisions taken across the design process and showing the suitability of these technologies to extend access to electricity. In the target projects, first, a preliminary analysis is carried out to estimate the energy resources and demand. Next, the system is designed and implemented to meet the demand using the available resources. The five projects illustrate different options for the electrical generation (single, hybrid or combination of technologies), storage (battery or diesel backup) and distribution (microgrid or individual systems), as well as different methods for data gathering and systems design. In addition, a comparison of projects' real behavior is carried out and their technical performance in terms of energy production and suitability of the technologies implemented is analyzed. These projects can be a good reference for the dissemination of such technologies in future projects in the Andean countries and abroad.

1. Introduction

Nowadays, about 1.2 billion people lack of access to electricity [1]. Over 95% of such population lives in developing countries and 84% in rural areas. Most rural communities without electricity are located in scattered territories with very low population density and where the national grid extension cost is very high. Consequently, an estimated 70% of communities must be electrified using isolated autonomous systems [2]. When considering sustainability-related aspects [3], diesel generators have many limitations, such as greenhouse gas emissions and external dependences on fossil fuels that can significantly increase the project costs. In contrast, autonomous electrification systems based on renewable energy take advantage of local resources and are increasingly being deployed [4], especially in developing countries [5,6].

Among the renewable energy technologies commonly used for autonomous systems, micro-hydro power plants take advantage of river waterfalls and flows to generate electricity, and represent a cheap and reliable option, though limited by the availability of nearby rivers [7]. Solar photovoltaic (PV) energy has been mainly used thanks to its availability almost everywhere in the world [8,9]. Meanwhile, small-scale wind energy receives increasing attention [10,11]. Finally, hydro-kinetic turbines, that produce electricity directly from river flows, have a low cost and can be installed in communities near rivers [12].

With regards to the distribution configuration, individual systems have generally been implemented (independent generation and storage for each consumption point), but they have limitations in the ability to

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http://dx.doi.org/10.1016/j.rser.2017.05.203
Received 13 September 2016; Received in revised form 16 February 2017; Accepted 22 May 2017
1364-0321/

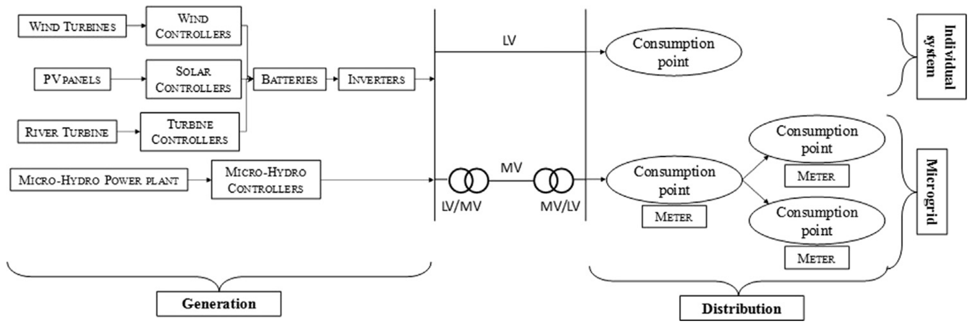

Fig. 1. Typical scheme for autonomous rural electrification systems with renewable energy.

include new users and adapt to demand increases. In contrast, microgrids (that concentrate generation and storage for several consumption points) have a greater flexibility in consumption, can reduce costs due to economies of scale, can take advantage of high resource areas and can improve cooperation between users, strengthening socioeconomic development [13]. All these advantages favor the use of microgrids in rural areas of developing countries [14].

Fig. 1 shows the common scheme for autonomous systems, which includes different optional generation technologies (wind, solar, micro-hydro and hydro-kinetic turbines) and distribution configurations (microgrids and individual systems). For wind turbines, PV panels and hydro-kinetic turbines, controllers protect batteries from overloads and deep discharges. Batteries store the energy to cover the mismatch between generation and consumption. After storage, inverters transform the DC current into AC, which is more suitable for residential appliances. Electricity is distributed to end-users either through microgrids (low or medium voltage, in which case transformers become necessary) or individual systems. Microgrids have a radial scheme, given its lower cost in front of other options. Finally, a meter can be installed at each point to control its consumption.

Relevant autonomous projects have been deployed in the three regions with the higher rural electrification requirements: Asia, Africa and Latin America. In Asia, for instance, in the island of Xiao Qing Dao (China), a microgrid was implemented, consisting of four 10 kW wind turbines, a 30 kW diesel generator, a 40 kW inverter and a battery bank; and its socioeconomic impact was well appreciated by end-users [15]. In fact, in China, the "Township Electrification Program" was launched in 2002, which was the largest renewable energy-based program in the world [16]. Under this framework, 51 wind-PV and 670 PV microgrids were installed in 20 months, providing electricity to more than 340,000 people. In the community of Buayan (Malaysia), a 14 kW micro-hydro power plant operates between 12 and 24 h, depending on whether the dry or rainy season, supplying 22 houses; while the remaining 18 houses are supplied by individual PV systems. Also in Malaysia, the community of Terian gets electricity from a 5 kW micro-hydropower plant [17]. In India, around 75,000 villages lack of access to electricity; and among the planned 2 GW power capacity expansion until 2022, an estimated 1.1 GW will be covered by microgrids. In the northern district of Leh, a 100 kW and a 40 kW PV microgrids with battery and diesel generator backup were deployed in the villages of Tangtse and Nyoma, respectively [18]. In the community Koyalapada, also in India, a 120 kW PV microgrid was deployed to provide lighting for 232 houses and feed a water pump located in a nearby aquifer [17]. The Indian government esteems that new microgrids will have an average capacity of 250 kW, mainly based on PV energy. Around one hectare per benefited community is needed for PV panels, in addition to the storage and diesel generators backup [19].

Since mid-2015, Africa is involved in an evaluation and planning process under the "Sustainable Energy for All" program of the United Nations. The program promotes microgrids as a technology to achieve the goal of universal access to energy [20]. By the end of 2015, 44 African countries had joined this initiative, and the Sustainable Energy Fund for Africa is already working on the development of microgrids in many of them. The Tanzanian government estimates that, through such programs, 250,000 people will be annually incorporated to the electricity service. As a first phase, hybrid PV/diesel/battery microgrids have been projected for 16 villages, 32 schools, 12 health centers and 77 religious buildings, thus benefiting 82,000 people [21]. Similarly, in the rural community of Ditunga (Democratic Republic of the Congo), a radio station, a school and a poultry farm were electrified through a wind/PV/battery microgrid. The project benefited 20,000 people, including 2000 school students [22]. In the community of Gada (Nigeria), a 5 kW microgrid based on hydro-kinetic energy was installed, providing around 15 kWh/day to 7 houses. The river has a seasonal flow, and a special channel was adapted to ensure generation even during the dry season [22].

In Latin America, the Brazilian government launched the program "Light for all" [23], through which the 89 houses of the Lenço island were electrified using a 40 kW wind-PV-diesel-battery microgrid [24]. In the largest Caribbean islands (Cuba, Dominican Republic and Haiti) renewable energy reached 22.8% of the energy matrix in 2006 [25]; mainly thanks to biomass. More specifically, the Cuban government is promoting the sustainable energy development of the Isla de la Juventud. In this island, the community of Cocodrilo, with 80 houses and 230 inhabitants, was electrified through a 50 kW microgrid whose primary energy source is biomass gasification [26].

Among the Latin American countries, this study is focused on Bolivia, Ecuador, Peru and Venezuela, which are part of the Andean region. These countries share most of their history, geography and demography, showing remarkable similarities in political, economic and social aspects. In this region, people live with a high economic dependence on natural resources, such as oil and mining. Foreign investment is mainly concentrated in such sectors, while rural-related activities are mostly abandoned [27]. For that reason, the population is concentrated in major cities and their suburbs, while 78% of the territory has a density lower than 50 inhabitants/km^2. All the countries in the region have made significant efforts to extend access to electricity within their territories, increasing between 1990 and 2012 from 67.0% to 90.5% in Bolivia, from 89.0% to 97.2% in Ecuador, from 69.0% to 91.2% in Peru and from 98.0% to almost 100.0% in Venezuela [28]. However, according to Fontaine [27], the abundance in fossil fuels, and consequently their low cost of opportunity, has a significant influence in delaying the transition of the energy matrix into renewable energy-based technologies. Therefore, rural electrification based in renewable energy represents a particular challenge in these countries. In fact, there are still 10.4 million people without electricity, especially in rural and remote areas [29]. This analysis of experiences focuses on such isolated zones, which concentrate the higher need for investment in electrification.

In this paper, five isolated renewable microgrid electrification projects in the Andean region are described and compared, illustrating some of the most used generation, storage and distribution technologies worldwide. These projects have been deployed by Non-Governmental