Renewable and Sustainable Energy Reviews 51 (2015) 182–196

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Hierarchical methodology to optimize the design of stand-alone electrification systems for rural communities considering technical and social criteria

B. Domenech [a,c,*], L. Ferrer-Martí [b,c], R. Pastor [a,c]

[a] Department of Management (DOE), Universitat Politècnica de Catalunya (UPC), Av. Diagonal 647, 08028 Barcelona, Spain
[b] Department of Mechanical Engineering (DEM), Universitat Politècnica de Catalunya (UPC), Av. Diagonal 647, 08028 Barcelona, Spain
[c] Institute of Industrial and Control Engineering (IOC), Universitat Politècnica de Catalunya (UPC), Av. Diagonal 647, 08028 Barcelona, Spain

ARTICLE INFO

Article history:
Received 21 November 2014
Received in revised form
27 April 2015
Accepted 1 June 2015

Keywords:
Design methodology
Stand-alone electrification
Wind-PV energies
Microgrids

ABSTRACT

Stand-alone electrification systems based on the use of renewable energies are suitable to electrify isolated rural communities in developing countries. For their design several support tools exist, but they do not cover some of the technical and social existing constraints and they do not consider the project detail. In this context, this research aims to develop a methodology to optimize the design of such systems, combining the wind and solar generation technologies as well as microgrids and individual systems as distribution scheme, and including economical, technical and social considerations. The design methodology is divided in three stages. First, the characteristics of the target community are gathered. Secondly, the design process is realized in three decision levels, ordered according to the importance of the decisions taken. At each level several electrification alternatives are generated and then the most appropriate is selected. Third, the final solution cost can be optionally tried to be improved, maintaining the decisions previously taken. The design methodology has been applied to a community to show its suitability to assist rural electrification promoters to design socially adapted and sustainable projects.

Contents

* Corresponding author at: Department of Management (DOE), Universitat Politècnica de Catalunya (UPC), Av. Diagonal 647, 08028 Barcelona, Spain. Tel.: +34 934 016 579.
E-mail address: bruno.domenech@upc.edu (B. Domenech).

http://dx.doi.org/10.1016/j.rser.2015.06.017
1364-0321/

1. Introduction

Nowadays around 1.3 billion people lack of access to electricity [1]; mainly in rural areas of developing countries [2]. To electrify this population, systems based on the use of wind and photovoltaic (PV) energies are a suitable option [3]. Both technologies complement to each other and allow attaining a great reliability of supply [4]. Due to the typical dispersion between houses in rural communities, usually individual systems are implemented [5]. As an alternative, projects that combine individual systems with one or more microgrids are increasingly being used, since microgrids have many advantages [6,7]. However, this combination entails a higher design difficulty, being necessary to plan the structure and connections of microgrids and to study a good compromise between their extension and possible cost increases when linking points [5].

Additionally, social considerations have proven to be a key issue to consider in the design of electrification projects [8,9,10]. For attaining a better projects' sustainability, the way they are carried out needs to be changed promoting high community participation during the design process [11,12]. Moreover, when considering several technical options inside a single community (such as wind, PV, microgrids and individual systems) a higher analysis of the social characteristics (as the community organization or the representative authorities) is particularly necessary to respect population preferences, and avoid social conflicts [13]. However, including social considerations in the systems design, in addition to economic and technical ones, significantly adds complexity to the projects' design process.

Due to the commented reasons, designed aid tools are needed to assess the decision-making when designing stand-alone wind-PV electrification projects. In this line, a general two-phase process is recommended [14]: first generating a set of efficient solutions or alternatives (Phase 1), utilizing optimization methods, and then selecting the most appropriate one (Phase 2), using multicriteria techniques. Thus, a great accuracy in the problem optimization can be attained and the decision-making can be carried out easily since the problem is known before deciding [15]. For example, OptElDec [16] sizes several technologies to supply isolated microgrids, simulates their performance and ranks them according to quantitative and qualitative criteria. However, the combination of technologies is not allowed and no detail of the electric distribution is offered. SURE [17,18] models different energy options for isolated communities in developing countries and selects the most appropriate according to physical, financial, natural, social and human criteria, using the compromise programming technique. Technologies combination is allowed, but the detail of the distribution and the decision-making process are not offered. Finally, Perera et al. [19] combine multi-objective and multicriteria techniques to design wind-PV systems supported by banks of batteries with a great detail of the energy resources, but they neither detail the distribution scheme.

Other works just focus on one of the two phases (alternatives generation or selection). Generally they are adequate for a specific problem but would have limitations if applied to other contexts. For the generation phase (Phase 1), most of the works combine several technologies to meet a specific demand, considering the detail of the energy resources, but without detailing the electric distribution scheme [20–24]. HOMER [25] and ViPOR [26] are widely used for designing electrification projects in rural areas of developing countries. HOMER designs the generation system, with a great detail of equipment and including many technologies, while ViPOR plans the distribution scheme. However, only one microgrid is allowed and combined with individual systems. Moreover, these works do not consider the social characteristics of the communities and the populations.

For the selection phase (Phase 2), in literature there is a tendency to start from a set of predefined scenarios and aim to choose the most appropriate one considering several criteria. In fact, including several criteria in energy planning is a key factor to attain projects' sustainability [10,27]. The process for this selection phase is usually structured in four points [28]: (1) criteria definition; (2) criteria weighting; (3) alternatives evaluation; and (4) results analysis and discussion. Most works partially or completely follow this structure using different multicriteria techniques [22,29–31]. Complementarily, to simplify the decision-making in the energy field, Thery and Zarate [32] propose the usual division in three levels: strategic decisions (high and long-term impact), tactical decisions (moderate and medium-term impact) and operational decisions (low and short-term impact). However, the way as the predefined scenarios are conceived or designed is generally not detailed.

In this context, this research aims to develop a methodology to design stand-alone electrification systems for rural communities, based on hybrid wind-PV energies, combining microgrids and individual systems and considering the detail of economical, technical and social characteristics of population. It is worth to highlight that including other generation technologies could use the same decision process and hierarchical framework. The design methodology is suitable to assist rural electrification promoters, allows studying a great amount of design options in a clear and structured framework and obtains solutions that match up end-users preferences. As result the most appropriate size and location of all the equipment to install is obtained, as well as the microgrids, their structure and the individual systems.

The methodology is organized in three stages. First, three assessments have to be realized to gather information about the community and its population. Secondly, the system design is carried out in three decision levels, ordered according to the importance of the decisions taken. At each level, a set of electrification alternatives is generated, studying a specific characteristic of solutions, and then the most appropriate alternative is selected based on several criteria. Two iterative procedures complement the process to adjust decisions when going in-depth into the problem. Finally, an optional third stage carries out a local optimization process maintaining the decisions previously taken. The functioning of the methodology is finally illustrated through