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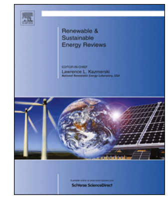

A hierarchical methodology for the integral net energy design of small-scale hybrid renewable energy systems

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ABSTRACT

In this paper a two level hierarchical methodology is presented for the integral design of hybrid power generation systems based on alternative renewable energy (ARE) systems using the net energy concept and considering technical, economical, societal as well as environmental aspects. Results are presented for the design of a small-scale hybrid renewable energy system using the proposed methodology in Margarita Island, Venezuela. The proposed methodology applies the integrated analytical hierarchy process (AHP) methodology to the selection of the best hybrid renewable energy system using the concept of net energy and is divided in two phases: a classic optimization process using levelized costs minimization and an AHP implementation for decision making problems. Under this methodology technical–economical aspects are considered as quantitative parameters, while social–environmental aspects depend largely on the criteria of the system planning engineers and future users of the system. Technical–economical aspects are considered using specialized software, used to optimize and compute the best configuration of an ARE project. Social–economical aspects are defined as a series of parameters that should be considered by the planning team, a meeting of experts or a community consensus on the project site. Several diesel price scenarios (low, intermediate and high) are considered. The results show the importance of the proposed tools for decision making problems.

Contents

1. Introduction

The future of the energy exploitation in our planet is bounded to many challenges such as the achievement of the diversification of the primary energy sources. Although recently oil prices have

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had an important decrease, the alternative renewable energy (ARE) sources are signaled to play an increasingly more important role in this diversification process. Renewable energy sources have grown from 0.1% of total of primary energy in 1973 (6106 MToe) to 1.1% of 13 371 MToe in 2013 [1]. This implies an increase of 2400% in 40 years, according to International Energy Agency [1].

Several reasons can explain the emergence of renewable energy as demography, conventional energy scarcity, equilibrium of planetary resource use. Climate change is a fact. Traditionally, the role of ARE sources has been referred to as part of the solution to global warming [2]. Also, 80% of global energy resources are used by 20% of the population living in developed countries [3]. ARE sources are an instrument to address the development of world population instead of using conventional energy resources.

Some advantages of ARE source are their participation on energy diversification, their modularity and the capability of decentralized operation. They may contribute to equitable geographical energy distribution in rural countries, and of course ARE source are environmental friendly when compared to some conventional sources as fossil fuel. In a regional context ARE sources are expected to play a more important leading role since wind energy sources show a significant development potential [4]. A very interesting comparison includes the concept of net energy, where the energy efficiency of the given sources is computed, namely a focus is given to "how much energy is needed to produce energy" [5]. In this net energy analysis, ARE sources are well placed when compared to hydrocarbon sources.

The analysis of the important role that ARE sources may play includes the following factors:

- Their participation in the energy diversification process.
- Inevitable participation in the national energy approach as conventional source are becoming scarce (as big scale hydropower), oil profitability should be maximized through exports, or due to immediate unavailability of some resources at big scale as in the case of natural gas.
- Identification of the political–territorial importance of ARE installations on remote and isolated sites, with special interest in strengthening the nationals developing axes.
- Active role of ARE source in network stability when considered as distributed energy sources with migration towards smart grids networks.
- Influence on the electricity balance and reduction of power transmission limits with installation of ARE sources near energy consumption centers.

The development of ARE resources are strongly dependent on energy decision makers preferences. These decision makers are generally energy stakeholders that participate in the energy market as investors and operators. In general, ARE projects are strongly encouraged by national or regional regulatory boards with strong incentives in order to achieve some economy of scale in alternative generating technologies. Within this context, when a energy decision maker prospects the implementation and use of ARE sources, an efficient methodology for a technical–economical selection is required.

There exists in literature several contributions about how to select an appropriate electrical generating scheme based upon ARE sources. A comprehensive review can be found in [6], with a survey of methodologies and computational tools to address this problem. We will highlight two of them. First, the RETscreen platform [7] provides an option for an initial analysis of technical and financial viability of potential renewable energy. Another well developed tool is HOMER [8], which is able to simulate and find the best selected option for energy source configurations in a given project. In this paper it is considered that the HOMER tool is known by the reader, however a detailed user manual is given in [8].

However, despite ongoing ARE evaluation methodologies have strong strengths on system optimization of technical and economic variables. It is observed that social and environmental aspects are hard to treat and valuate in these proposals. Quantifying and evaluating the social and environmental viability of a project is a difficult task. The analytic hierarchy process (AHP) can be applied as a complementary evaluation technique in order to evaluate societal and environmental impact aspects of widespread integration of ARE sources. The methodology, proposed and developed in [9], gives the possibility of classifying the different analysis criteria into a hierarchical model, thus solving the problem of selection between several solution alternatives. The use of a defined weighting system makes it easier to classify alternatives an criteria entries by applying a pair-wise comparison. We can find some background on AHP application for ARE planning purposes. Comprehensive reviews on AHP application for ARE resource planning and project valuation can be found in [10–12]. In the following we discuss some of them. An analytic hierarchy process has been applied by [13,14] for renewable energy resources in Jordan. The application of an AHP method for Chinese ARE sources is found in [15,16]. In [17,18] the use of the AHP method is proposed for decision making and planning of ARE generation projects in Canada and India respectively. Similarly, in [19,20], the AHP method is applied for renewable energy planning in Malaysia and Indonesia respectively. An integrated VIKOR–AHP methodology to the selection of the best energy policy and production site is developed in [21]. In the work presented in [22], an integrated methodology is proposed combining linear optimization and AHP. The use of different, advanced techniques along with the AHP method has also been formulated in the literature. In [23,24], fuzzy logic is used for the AHP approach for an ARE application in Brazil and Korea respectively. An analysis of the energy return on energy invested impact of ARE sources to the environment is presented in [25].

This paper presents an integral approach that considers a technical–economical analysis for ARE sources technology selection, but also societal–environmental aspects are considered during the analysis of the project, considering the net energy or EROEI concept [26]. The use of a two level analytic hierarchy process

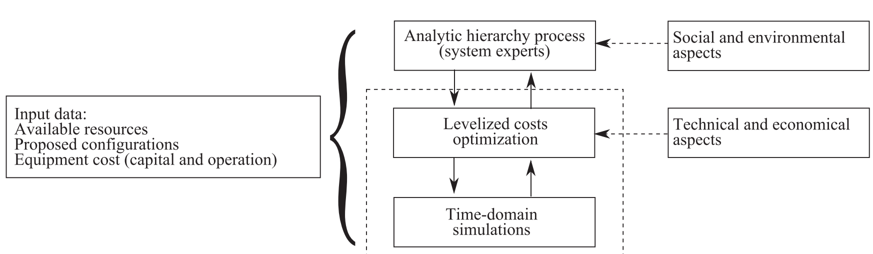

Fig. 1. Proposed methodology.