Computers & Operations Research 71 (2016) 90–99

Contents lists available at ScienceDirect

Computers & Operations Research

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

MILP-based heuristics for the design of rural community electrification projects

Joan Triadó-Aymerich [a], Laia Ferrer-Martí [b], Alberto García-Villoria [b,*], Rafael Pastor [b]

[a] Escola Superior Politècnica de Mataró, Pompeu Fabra University, C/ Ernest Lluch 32, Mataró, Spain
[b] Institute of Industrial and Control Engineering, Universitat Politècnica de Catalunya- Barcelona Tech (UPC), Av. Diagonal 647, Barcelona, Spain

ARTICLE INFO

Available online 30 January 2016

Keywords:
MILP
Heuristics
Rural electrification
Wind–photovoltaic systems

ABSTRACT

Wind–photovoltaic systems are a suitable option to provide electricity to isolated communities autonomously. To design these systems, there are recent mathematical models that solve the location and type of each of the electrification components and the design of the possible distribution microgrids. When the amount of demand points to electrify increases, solving the mathematical model requires a computational time that becomes infeasible in practice. To speed up the solving process, three heuristic methods based on mixed integer linear programming (MILP) are presented in this paper: Relax and Fix heuristics, heuristics based on a Corridor Method and Increasing Radius heuristics. In all algorithms first a relaxed MILP is solved to obtain a base solution and then it is used as a starting point to find a feasible solution by searching in a reduced search space. For each type of heuristic several options to relax and to reduce the solution space are developed and tested. Extensive computational experiments based on real projects are carried out and results show that the best heuristic vary according to the size of instances.

1. Introduction

Over 1.3 billion people worldwide lack access to electricity, especially in rural areas of developing countries [1]. In some regions access to conventional electricity grid is very difficult due to the complexity of the terrain and the dispersal of populations. In these cases, a suitable alternative to provide contact to electricity are autonomous systems based on the use of renewable energy sources [2,3] since they promote the sustainability of the projects due to the handling of local sources thereby avoid external dependencies, and tend to be cheaper than the extension of the conventional electricity grid.

Photovoltaic systems (PV) have been widely used in recent decades to electrify rural communities. On the other hand, wind systems are increasingly being used [4,5], e.g. Compared with PV, in windy regions the use of wind systems may be more profitable, especially if demand increases and powerful turbines are used. On the other hand, hybrid systems are more efficient, providing more supply reliability and consequently, requiring less energy storage if compared with single energy resource systems [6,7].

In autonomous electrification networks, individual systems at each demand point are typically used [8]. However, microgrid distribution arrangements, in which energy is produced in a specific point and distributed by the electric grid to other demand points, have advantages [9,10]. Its implementation could imply significant savings in the investment cost compared with individual systems, taking advantage of the best resource areas and economies of scale. The combination of microgrids and individual systems (points individually fed) may be the best solution in dispersed communities and it was incorporated in [11].

Due to the complexity of designing hybrid systems, in the last years different methods to assist designers have appeared. Most of them are focused exclusively on the definition of the best combination of energy resources [12–15] but not on the distribution grid design. Others consider both problems although all the points must be connected to one only grid [16–18]. There are few references that deal with autonomous electrification systems designs using hybrid systems and microgrids or individual systems at the same time [11,19,20].

The use of optimization methods is increasingly a powerful tool for solving real-life problems as the design of electrification systems using renewable energies [21,22]. Especially, linear programming has been widely used in recent years [23–25] on the conception of energy systems. A MILP model to scheme wind electrification projects that combine microgrids and individual systems has been presented in [20]. Afterwards, a new model was developed in [11] incorporating solar generation. The last aforementioned model has been used in projects at Peru [5] and Cape Verde [26] in order to optimize the design of all the components of autonomous electrification systems: solar panels and wind

* Corresponding author.
E-mail address: alberto.garcia-villoria@upc.edu (A. García-Villoria).

http://dx.doi.org/10.1016/j.cor.2016.01.010
0305-0548/

Nomenclature

Demand points location of consumption points (users), such as houses or public buildings to electrify
Microgrid set of demand points connected to each other and fed by the same generation system placed at one of the demand points
Community the group of users
Connection the existence of cable (regardless its type) between two demand points

turbines, electric equipment and cables. The model considers voltage drops and the variability of wind resource according to the placing of generation in demand points.

However, the application of mathematical models to solve this kind of hard combinatorial optimization problems (COPs) is not practical when the size of instances increases, since they spend high computational times. For that reason, heuristics are commonly used to solve COPs [27] in order to obtain solutions reasonably close to the optimal or near optimal solutions in a practical time. For instance VIPOR is a simulated annealing method which designs autonomous electrification projects considering hybrid generation, microgrids and spatial variation of resources [19,28]. VIPOR determines the location of generation and the distribution grid but with some technical limitations; in particular, it assumes uniform resource in all the points for individual generation and does not calculate voltage drops. A recent study has been presented developing a set of indicators to support the design of autonomous electrification projects [29]. These indicators can be used to select the potential generation points. Furthermore, it evaluates heuristically the suitability of the points to be (or not) connected to a microgrid. A heuristic is also presented in [29] to obtain quickly single-microgrid solutions; i.e., solutions constrained to no more than one microgrid.

To the best of our knowledge, heuristic methods based on MILP have not been applied to autonomous electrification projects although they have been applied successfully in other kind of grid systems problems [30,31]. In this paper we present heuristic methods based on a MILP model to solve the problem of autonomous electrification systems formed by microgrids powered by solar and wind generators located at one of the points in each microgrid, and allowing the possibility of containing individual systems. The following three type of MILP-based heuristics are presented: Relax and Fix heuristics, Heuristics based on the Corridor Method and adhoc developed heuristics that we call Increasing Radius. Instances with high number of demand points are tackled in this work and results show the best heuristic to use depending on the size of the instance.

The paper is organized as follows. Section 2 presents the problem and the components of the autonomous electrification project. Section 3 describes the MILP model in which the proposed heuristics are based. In Section 4 the heuristics are presented. In Section 5, computational experiments are carried out to evaluate and compare the performance of the algorithms. Finally, Section 6 concludes this paper.

2. Rural autonomous electrification project

The rural autonomous electrification project presented in this paper considers wind and solar generation placed in demand points. The design of these systems must take account of the availability of these energies in the region (wind resource maps and irradiation data). The electricity distribution combines individual systems and microgrids. The problem is to define which demand points will be included in each microgrid, or whether they will be individually fed; where generators and other components will be placed, and which and how many components are to be used, so as to minimize the initial investment satisfying the demand together with other technical constraints.

The components of the autonomous electrification project (Fig. 1) are, first, the wind or photovoltaic (PV) generation equipment, which include the generators and the regulators. Next, are the batteries to store energy and the inverters to create alternating current (AC). Finally, there are the cables that distribute the electricity with radial microgrids [32] and meters at the demand points (e.g., houses) for measuring for measuring energy consumed. Each component of rural electrification project can be of different types in order to adequate the design to the needs of each zone.

The energy generated by a wind generator of a particular type depends on the wind resource at a specific demand point. On the other hand, the energy produced by a PV generator (solar panel) of a particular type does not depend on its location because the solar resource is considered uniform in all parts of a community [33]. The number of solar and wind generators are limited at a specific

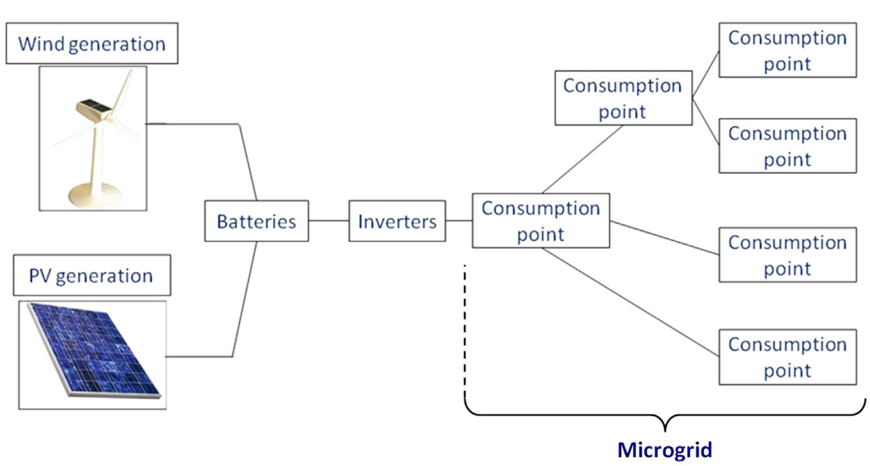

Fig. 1. Scheme of rural autonomous electrification systems [11].