Design of electrification projects for communities in the Amazon Region of Ecuador

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Abstract

Nowadays, 1.2 billion people still lack of access to electricity. Autonomous systems based on renewable energy sources are an appropriate alternative extend electrification, in particular for Ecuadorian Amazon Region (RAE). The objective of this work is to propose a tool to design of autonomous electrification systems for rural isolated communities of RAE, using photovoltaic technology and micro-grid or individual systems, and taking into account technical, economic and social aspects. For this purpose, a mixed integer linear programming model is developed that solves the type and number of equipment to install and where to place each of them, as well as the distribution micro-grids. The tool has been validated in the design of the electrification system of the community of Conambo.

1. Introduction

Nowadays, 1.2 billion people still lack of access to electricity [IEA 2015]. Most of this population live in rural areas of developing countries. To give access to electricity, the most common strategy is the extension of the national electricity grid, but it is often too expensive to reach remote and dispersed areas (Ahlborg & Hammar [2014]). Indeed, most rural communities without electricity are located in scattered territories with very low population density and, thus, where the national grid extension cost is very high. As an alternative, autonomous isolated systems are a suitable option to extend electrification, for which different generation and electrical distribution options are feasible (Palit & Bandyopadhyay [2016]). Consequently, an estimated 70% of communities must be electrified using isolated autonomous systems [IEA 2011].

In recent years, Ecuador's energy sector has made progress in terms of electricity coverage in the country, although this progress has been unevenly distributed in the territory. The improvement is observed in the areas where the national electricity grid has been able to reach, but the great challenge is the electrification of isolated rural areas: dispersed communities with a level of electrification almost non-existent and to which access to electricity by grid becomes unfeasible.

The Ecuadorian Amazon Region (RAE), where isolated rural areas have small and scattered population centres, represents 40% of the Ecuadorian territory (Feron et al. [2016]). Historically, in this region the extension of conventional electricity grid has been seen as an option with many technical difficulties, economically very deficient and environmentally very invasive. Due to the lack of electricity service, these isolated communities have not been able to meet their communication, lighting and development needs, which have widened the inequality and marginalization of this region with the rest of the country. In this context, autonomous electrification systems based on renewable energy sources are a viable social, environmental, technical and economic alternative, with a high degree of respect for the development of communities and that minimize environmental impacts in an ecologically sensitive area.

The objective of this work is to propose a tool to design of autonomous electrification systems for rural isolated communities from the RAE, using photovoltaic technology and micro-grid or individual systems, and taking into account technical, economic and social aspects. For this purpose, a mixed integer linear programming (MILP) model has been developed considering the needs of the population, the characteristics of the region, the availability of local resources and equipment, among others. The result obtained solving the MILP is the type and number of equipment to install, and where to place each of them, as well as the distribution micro-grids that have to be installed. The tool has been validated in the design of the electrification system of the community of Conambo.

2. Isolated electrification systems in RAE

The most common autonomous electrification technologies used in isolated rural communities are: diesel, wind, hydro and solar generators. Among them, photovoltaic technology is the current commitment of the Ecuadorian government for the electrification of the region. Briefly, the main arguments are: the extensive knowledge of the country's technicians regarding this technology, its relationship between price and ease of installation, and it is the renewable option that best fits with the conditions and characteristics of the region. Solar technology produces electrical energy from solar radiation, transforming it through a photovoltaic cell. The production of energy depends on the solar cycle and, therefore, it needs an accumulation system (batteries) to guarantee the supply during the night or on cloudy days.

Autonomous photovoltaic electrification systems are formed by a set of photovoltaic generators, regulators, batteries and inverters, to be sized depending on the electrical energy produced by the generator for the final application of the user. An autonomous electrification system can satisfy a single demand point, individual system, or also different demand points feed from a single generation point of a micro-grid. In this work, both the use of individual systems and micro-grids (with centralized generation in a single point and radial distribution) is combined, if this is the most appropriate solution. In addition, generation is allowed in non-consumption points, which implies building a booth near the panels to locate the regulators, batteries and inverters. In addition, in order to guarantee that all the users of a micro-grid consume the energy that corresponds to them, a meter-limiter of energy is needed.

In addition, specific conditions of the RAE are included in the design of electrification systems:

• General conditions of RAE: 1) Regulations regarding the details and technical specifications of isolated photovoltaic systems of Ecuador; 2) The use of underground instead of aerial micro-grids due to social, environmental and technical constraints of the Lower Amazon; 3) Electrical distribution, considering that the distribution boxes that are used have space for three cables: 1 input and 2 outputs.
• Specific limitations for the community to be electrified: 1) Communication channels (which may limit the availability of equipment to be used) and non possible connection points (runway, flood zones, rivers, ...); 2) Minimum acceptable number of demand points to be able to form a micro-grid (currently between 6 and 8); 3) Possibility of accepting micro-grids even if they are a certain percentage more expensive than individual systems; 4) Cost of purchase and installation of booths if generators are installed at a non-consumption point.

3. Tool for the design of electrification systems

The use of optimization methods is increasingly becoming a powerful tool for solving real-life problems as the design of electrification systems using renewable energy [Baños et al. (2011), White et al. (2013)]. The literature related to the design of stand-alone electrification systems, mainly focuses on combining technologies to meet a specific demand, without studying the detail of the electricity distribution configuration [Bernal-Agustín & Dufo-Lopez (2009)].

In this work, a MILP model has been developed, which provides the best configuration of generators and micro-grid distribution for the community studied, defining in detail the types of equipment to be installed at each point: photovoltaic panels, regulators, batteries, inverters, limiters and the cables of the micro-grids. The MILP is based on previous models (Ferrer-Martí et al. [2013] and Domenech et al. [2015]) and, in addition to the general characteristics of this type of systems, incorporates the specific conditions in the RAE: matrix of possible connections, maximum number of output cables in micro-grid, minimum number of users per micro-grid, and cost of construction of a booth and the weighting of the cost of micro-grid.

Next, the parameters, variables, objective function and constraints of the model are described (Ranaboldo et al. [2014]).

Parameters:
– Demand: Energy and power requirements of each consumption point (houses, schools, health centers, etc.) and days of autonomy.
– Generation and accumulation: PV panels (types, cost, nominal power, energy generated and maximum number at one generation point) and batteries (types, cost, capacity and discharge factor).

– Definition of the network: Distance between points, cables (types, cost per meter including micro-grid infrastructure, resistance and maximum intensity), nominal voltage and maximum voltage drop.
– Equipment: Controllers and inverters (types, cost and maximum power) and meters (cost).

Variables:
– Equipment (generation, accumulation, distribution): Integer variables indicating the number of each type of equipment to be installed at each point.
– Definition of the network: Binary variables indicating if two points are connected with a type of clable, and real variables for power and energy flows between two points.

Objective function: minimizes the cost but weighting the costs depending on the installation of the individual systems and the micro-grids.

Constraints:
– Generation and accumulation: At each point, an energy and power balance is realized. Batteries must be installed in generation points and its capacity must cover the days of autonomy, considering the demand and the discharge factor.
– Definition of the network: The relationship between energy and power flows and the existence of a cable is established. The installed cable must satisfy the maximum voltage drop and maximum intensity. The micro-grid structure is radial. The maximum number of output wires in micro-grids; and the minimum number of users per micro-grid.
- Equipment: Installed solar controllers must be adequately powered for PV panels. Inverters must satisfy the power demand. Controllers and inverters must be installed in generation-accumulation points.

4. Design of the electrification system of Conambo

The developed tool is applied to the community of Conambo, in the Lower Ecuadorian Amazon. Conambo is a very isolated community (only accessible by plane), without basic services (drinking water, water drainage systems or access to electricity), with a very low level of development. In Conambo batteries, kerosene lamps and candles are used for lighting. The nearest point with national electricity grid is 130 km away. The demand data, as well as the energy generation data, the installation equipment and the limitations of the definition of the grid have been obtained with field visits.

Conambo is a community formed by 46 families and 14 other constructions (a communal centre for meetings, school classrooms, community kitchens, etc.), which represents 60 demand points. In addition to the 60 demand points, 6 possible generation points are considered (with no demand). The community may be geographically divided in 5 areas: lower side A (12 points), lower side B (15 points), lower side C (22 points), lower side D (7 points) and upper side (10 points). The proposed solution obtained with the MILP model is:

• Lower side A, 10 demand points and 2 possible generation points: a single micro-grid for the 10 demand points, generating at a non-demand point.
• Lower side B, 14 demand points and 1 possible generation point: a single micro-grid for the 14 demand points, generating at a non-demand point.
• Lower side C, 21 demand points and 1 possible generation point: a micro-grid for 11 demand points, generating at a non-demand point, and 10 individual generation systems.
• Lower side D, 6 demand points and 1 possible generation point: 6 individual generation systems.
• Top side, 9 demand points and 1 possible generation point: 9 individual generation systems.

5. Conclusions

A useful tool has been developed for the design of isolated rural electrification systems in the Amazonian Region of Ecuador, to ease access to electricity for isolated populations in the region. The proposed MILP model considers technical, economic and social aspects of the region. It has been successfully applied in design of the electrification system of the community of Conambo and the solution obtained combines the use of micro-grids and individual systems. Autonomous photovoltaic electrification systems are a socially, environmentally, technically and economically sustainable solution for the rural Amazonian population, while respect and promote their development.

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