Energy 117 (2016) 47–57

Contents lists available at ScienceDirect

Energy

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

Design of maintenance structures for rural electrification with solar home systems. The case of the Moroccan program

L.M. Carrasco [a, *], F.J. Martín-Campo [b], L. Narvarte [a], M.T. Ortuño [b], B. Vitoriano [b]

[a] Instituto de Energía Solar (IES) – Universidad Politécnica de Madrid (UPM), Carretera de Valencia km 7, ETSI y Sistemas de Telecomunicación, IES, 28031, Madrid, Spain
[b] HUM-LOG Research Group, Universidad Complutense de Madrid, Plaza de las Ciencias 3, Madrid, 28040, Spain

ARTICLE INFO

Article history:
Received 30 April 2015
Received in revised form
4 October 2016
Accepted 19 October 2016
Available online 26 October 2016

Keywords:
Rural electrification
Operation & maintenance
Optimisation model

ABSTRACT

In decentralised rural electrification through solar home systems, private companies and promoting institutions are faced with the problem of deploying maintenance structures to operate and guarantee the service of the solar systems for long periods (ten years or more). The problems linked to decentralisation, such as the dispersion of dwellings, difficult access and maintenance needs, makes it an arduous task. This paper proposes an innovative design tool created *ad hoc* for photovoltaic rural electrification based on a real photovoltaic rural electrification program in Morocco as a special case study. The tool is developed from a mathematical model comprising a set of decision variables (location, transport, etc.) that must meet certain constraints and whose optimisation criterion is the minimum cost of the operation and maintenance activity assuming an established quality of service. The main output of the model is the overall cost of the maintenance structure. The best location for the local maintenance headquarters and warehouses in a given region is established, as are the number of maintenance technicians and vehicles required.

© 2016 Elsevier Ltd. All rights reserved.

1. Introduction

Human development is a concept that has evolved over the years. In recent times, this has included access to basic services, such as electricity [1]. In the so-called developing countries, most remote rural areas do not have access to electricity grids (an example is India, that had up to 400 million people without access to electricity in 2011 [2], concentrated in the poorest states of the country [3]). Photovoltaic rural electrification (PVRE) represents, in many cases, the only hope of accessing electricity [4]. A recent study [5] shows how regions in developing countries with a low density population favour stand-alone solutions for providing access to energy. A good example is the case of remote regions in Mali [6], where PVRE has been implemented as a sustainable energy solution for rural villages. PVRE has gone through a change of scale during the last decade in terms of size and sustainability, which has given rise to the development of large-scale programs with thousands of solar home systems (SHS) and long operation and maintenance (O&M) service periods. Bangladesh is a paradigmatic example with more than 4 million solar home systems installed up to July 2016 [7]. The *fee for service* financial model [8] has largely been adopted in many of these programs devolving the responsibility for the implementation and management of the programs to specialized energy service companies (ESCO), as in South Africa [9], Zambia [10] or Morocco in the PERG program [11].

Nevertheless, these ESCOs have face to the problem of decentralisation (remoteness and dispersion of the SHSs), which leads to high maintenance management costs. Traditionally the ESCOs have to design the O&M based on assumptions such as the lifetime of the SHS components provided by the manufacturers in the datasheets or by considering the yearly maintenance cost as a ratio of between 1% and 3% of the investment cost (cost of providing and installing the SHSs), as reported in Refs. [12] and [13], without considering that these assumptions have never been properly compared with the real situation. This common practice has led to the failure of many PVRE programs in recent decades as a result of the excessive costs derived from the O&M services, leading many ESCOs to abandon the programs because of the negative financial balances. Despite the lack of reporting, the cases of South Africa (see Refs. [9] and [14]) or Morocco, the latter well known by the author, can be cited. According to [15] among others, the main challenge for the

* Corresponding author.
E-mail address: luismiguel.carrasco@ies-def.upm.es (L.M. Carrasco).

http://dx.doi.org/10.1016/j.energy.2016.10.073
0360-5442/© 2016 Elsevier Ltd. All rights reserved.

Acronyms

Ah	Ampere hour
CM	Corrective Maintenance
ESCO	Energy Service Company
GAMS	General Algebraic Modelling System
LC	Low power Consumption light lamps
MTTF	Mean Time To Failure
O&M	Operation and Maintenance
ONEE	Office National de l'Electricité et l'Eau *(Morocco)*
PERG	Program d'Electrification Rurale Globale *(Morocco)*
PM	Preventive Maintenance
PV	Photovoltaic
PVRE	Photovoltaic Rural Electrification
PWM	Pulse-Width Modulation *(charge controller)*
SHS	Solar Home Systems
Si	Silicon
SLI	Start-Lighting-Ignition *(Battery)*
SOC	State Of Charge
Wp	Watt peak

fee for service model is to organise the operation and maintenance of the systems and fee collection in a financially sustainable way. In fact, decentralisation adds uncertainty the O&M costs, depending on aspects such as the geographical density of the SHSs, their actual reliability in operating conditions, road access [16] or the different local costs (salaries, vehicles, fuel, taxes, etc.). To date no cases of the systematic use of maintenance structure design tools based on actual data are known in the field of PVRE.

To tackle this deficiency, the objective of this paper is to carry out a first approach of an *ad-hoc* tool for the design of maintenance structures for PVRE programs in decentralised areas, with the aim of minimising the O&M costs. This tool has been developed for an actual PVRE program carried out in Morocco as a case study, whose inputs are not traditional assumptions but real figures as regards the actual reliability of the SHS components in this program, the O&M structure deployed and their costs. Similar *ad hoc* tools have been developed in the field of rural development [17] and electrification through renewable energies [18]. However, to our knowledge, there are no reported cases in the field of O&M in PVRE using SHSs. As this study is restricted to this particular program, it is not the aim of the authors to present this tool as a general solution but to show the potential benefits of its application to this kind of PVRE program. Adaptations of this tool could be useful for other programs with different kinds of technical features and management requirements.

The methodology used in the research work is based on the development of a mathematical optimisation model [19], applied to the PVRE program carried out in Morocco, the so-called *Programme d'Electrification Rurale Global* (PERG) [20], as a representative case of the *fee-for-service* initiatives carried out worldwide. The authors have had access to the 5-year maintenance and cost databases of the PERG program from between 2006 and 2010, provided by the ESCO, ISOFOTON, as well as the organizational and management structure deployed by the ESCO during that period. The maintenance of the PERG program has already been analysed in three previous papers in which the reliability study of the SHSs [21], the degradation of batteries and PV modules [22] and the O&M cost assessment [23] were set out. The proposed optimisation model has been implemented using GAMS [24], one of the most powerful algebraic modelling languages, and solved using the CPLEX optimiser [25], which uses a branch-and-cut procedure [26]. The input data required has been defined together with several variables and restrictions. An objective function for computing the cost of the O&M services is optimised, and the following outputs have been obtained:

- composition of the maintenance structure (number of technicians and vehicles),
- location and number of local agencies (local maintenance headquarters and warehouses),
- scheduling of preventive maintenance and the collection of fees,
- total cost of the services.

A prototype model has been implemented and validated in three of the nine provinces of the PERG region in order to show how this tool can be useful in helping ESCOs in the design of the maintenance structures in PVRE programs.

2. Perg program baseline data

The Moroccan PERG program was carried out by different ESCOs in partnership with the national utility; the *Office National d'Electricité et l'Eau* (ONEE) [27]. Our study focuses on the program carried out by the ESCO ISOFOTON, one of the participants in the program, which started in 2005 in a vast and mountainous area of around 200,000 km^2, and with 13,452 installed SHSs.

The ONEE, as the promoter of the electrification program, established the technical, financial and organizational conditions, which the ESCO had to follow in the development of the program. The PERG was set up as a *fee for service* model, so the ESCOs were responsible for the marketing, sales, installation and operation & maintenance of the SHSs in accordance with the following principles set out by the ONEE:

- The SHS cost is 90% subsidized by the utility. The remaining 10% is paid by the user through a fee collected by the ESCO (around €70).
- The SHS model is sized and standardized by the ONEE for the whole concession (Fig. 1).
- The user signs a subscription contract with the ONEE, and a second contract with the ESCO and the ONEE for the O&M service.
- The time required for installing the SHS is 2 weeks from signing the contract and paying the subscription fee.
- The ONEE utility is the owner of the SHS.
- The 10-year maintenance period begins after installation. During this period the ESCO has to guarantee the service of the SHS, replacing any components that fail.
- The ESCO had to train the customers only in the use of the SHS, as the maintenance work is the responsibility of the ESCO
- During the O&M period the user has to pay a monthly fee of around €5 (taxes not included) to the ESCO corresponding to the maintenance service
- The ESCO is required to have a free phone number available for the customers in case of a fault in the SHS or any of its components.
- The ESCO has to repair or replace every defective or malfunctioning SHS component within 48 h from being notified by the user (corrective maintenance).
- The ESCO must visit every SHS at least once each 6 months to check the state of the SHS and to fill the battery with distilled water (preventive maintenance).
- The ESCO has to maintain an O&M local structure to carry out the aforementioned service.

Download English Version:

https://daneshyari.com/en/article/5477209

Download Persian Version:

https://daneshyari.com/article/5477209

Daneshyari.com