Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 135 (2017) 367–378

Energy Procedia

www.elsevier.com/locate/procedia

11th International Renewable Energy Storage Conference, IRES 2017, 14-16 March 2017, Düsseldorf, Germany

Novel LoadProGen procedure for micro-grid design in emerging country scenarios: application to energy storage sizing

S. Mandelli[a], C. Brivio[b], M. Moncecchi[b], F. Riva[b], G. Bonamini[b], M.Merlo*[b]

[a]*CESI S.p.a., via Rubattino, 20134 Milano, Italy*
[b]*Energy Department, Politecnico di Milano, via la masa, 20156 Milano, Italy*

Abstract

This paper is devoted to describe the development, implementation and application of a novel procedure to properly design the electrification process in rural areas of Emerging Countries (EC). The procedure exploits a *bottom-up* approach, i.e. target applications are related to micro-grids devoted to satisfy the electrical needs of small communities. The procedure starts from microscopic data (i.e. single electric appliances) to effectively catch the customer needs (i.e. *bottom*) and it matches them with the available energy sources in the target area. In particular, a tool named *LoadProGen* developed by the Energy4Growing research group of Politecnico di Milano, is presented: the mathematical approach proposed is detailed and a real field case study relevant to a micro-grid deployed in Tanzania is provided. The tool is based on the gathering of information about the target area, i.e. to get information from interview and field audit, and on a stochastic approach to build up realistic estimation of the electric load profile of the considered uses. The energy needs forecast (cfr. load profile) is then adopted in a second procedure devoted to design a micro-grid capable to properly feed the loads. In this work, for sake of exemplification, this latter is supposed to be a photovoltaic based micro-grid integrated with an electrochemical storage.

Keywords: Microgrid; Emerging Countries; Electrochemical Energy Storage; Photovolatic; Energy Design.

* Corresponding author. Tel.: +39 0223993762; fax: +39 0223998566.
E-mail address: marco.merlo@polimi.it

10.1016/j.egypro.2017.09.528

1. Introduction

Small-scale off-grid power systems (hundreds of kW) represent probably the most viable solution, in the short scenario, to the problem of access to electricity in rural areas of emerging countries (ECs). Despite a centralized electrification could be more efficient and cost-effective, governmental weaknesses and utilities indifferences towards the less productive areas of their countries have speed up the diffusion of decentralized off-grid systems in the last decades. Discussing about rural areas electrification process, one of the most critical problem is the evaluation of the energy needs and, consequently, the design of an electrical infrastructure capable to properly feed the loads.

In literature several approaches are proposed, nevertheless a common accepted approach is still missing. Sinha and Chandel [1] suggest to size carefully an energy system when based on real load variation, to limit the risk of under- or oversizing. In situations of rural electrification programs, Cabral et al. [2,3] and Kivaisi [4] stress the importance to correctly estimate electricity demand. Celik [5] discusses about the need of sizing off-grid photovoltaic systems using detailed load profiles, while Mandelli et al. [6] suggest how the optimum off-grid PV system configurations are significantly affected by load profiles. In this context, the need to identify a robust approach to forecast daily load profile clearly emerges. Theo et al. [7] reviews several works that determine load demand often using hourly time resolution and time frames of one day, and onsite measurement, as data source. Daily load profiles are often generated using arbitrary and unstructured approaches [8], without clearly indicating where they come from [9], or employing or adapting load curves of similar contexts ([10,11]), or by relying on some consideration about the functioning periods of electric appliances and/or load factors ([12–14]). Such an approach could drive to consistent underestimation or overestimation of the energy needs and, consequently, to an ineffective design of the micro-grid.

Pflugradt [16] developed a modelling tool for residential energy consumption (i.e. electricity, gas, residential hot and cold water) in developed regions, which simulates the behaviour of people in a household to generate load curves. Since it is focused at individual household level, the software does not provide any load curves for commercial buildings, and it is not appropriate for simulating populations above about a 1000 people. In the specific context of developing countries, Boait and Gammon [15] rely on the central limit theorem and Monte Carlo simulation to aggregate and then derive a possible electricity demand arising from a pool of intermittent and stochastic profiles. Mandelli et al. [8] introduce a novel new mathematical bottom-up stochastic procedure, which they formalized in the software LoadProGen (Load Profile Generator) implemented in MATLAB®, whose developments and implementation are presented in this paper.

2. LoadProGen Mathematical model

LoadProGen is a tool devoted to formulate daily load profiles, properly describing users' energy consumptions uncertainty (i.e. properly representing the stochastic nature of the load profiles).

LoadProGen is based on a bottom-up approach: load profiles are built from users' electric needs and habits that can be estimated or collected by interviews, audits, etc. . To do this, users are divided into different classes so that within each class users have the same type and number of appliances, and they use them with a similar behaviour. Considering the coincidence behaviour of the appliances, the tool defines the switching on instants for each appliance within each class and it obtains a daily load profile for the single user class; repeating this process for each user class, at the end it sums the profiles of the classes to find the total load profile. Specifically, a single user class profile is computed by means of the procedure schematically depicted in figure 1 that is shortly explained in the following paragraphs. With regards to the definition of the inputs of the procedure, in rural areas of emerging countries the data gathering is supposed to be based on audits and interviews devoted to identify the needs and to evaluate the possible energy behaviour of the users. Obviously, the collected data are characterized by high uncertainty in some parameters; consequently the modelling approach is not based on "crisp" variables, but on a statistical-like description of the needs.

In particular, the adopted model to evaluate the needs is based on the following inputs:

- Users are classified in classes and for each class j the total number of users represented (N_j) is detailed;
- Each appliance i in use by a single user in the class j is described by:
  - Nominal power of the appliance (P_{ij});
  - Number of appliance i used by a single user (n_{ij});