Energy for Sustainable Development 43 (2018) 186–195

Contents lists available at ScienceDirect

Energy for Sustainable Development

Comparison of load profiles in a mini-grid: Assessment of performance metrics using measured and interview-based data

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ARTICLE INFO

Article history:
Received 1 September 2017
Revised 26 January 2018
Accepted 26 January 2018
Available online xxxx

Keywords:
Rural electrification
Load profiles
Load assessments
Mini-grids

ABSTRACT

Mini-grids are seen as an important option for increasing access to electricity in non-electrified rural areas where grid-extension is unfeasible. Appropriately dimensioning and constructing mini-grids requires knowledge of electricity usage. There is currently a lack of measured load profiles from mini-grids and the most common method for estimating electricity usage is through appliance data collected via interviews. Thus, this paper compares and investigates the differences between measured daily load profiles and daily load profiles created from appliance data collected through interviews and how the two methods impact the dimensioning and operation of a mini-grid. This is done by comparing load profiles for an entire mini-grid, a household and SME customers with large loads. The paper reports differing results from the two methodologies. Generally, the results show that the interview-based load profiles fail to provide an accurate overall estimate. The calculated performance metrics for the two methods also shows large differences. The interview-based load profiles mainly fail to provide accurate estimates of energy and the energy related (capacity factor and load factor) performance metrics. Accordingly, the implications for mini-grid operators and developers could be significant. The interview-based load profiles indicate the mini-grid system to be considerably less technically and economically desirable than measurements show. Suggestions for how the interview process can be improved are presented.

Introduction

Over one billion people lack access to electricity in the world as of today. Most of these people live in remote rural areas in sub-Saharan Africa and developing Asia (IEA, 2015). Improving access to modern energy sources is considered an important goal in combating extreme poverty. It is the 7th of the Sustainable Development Goals (United Nations, 2015) and the primary objective of the Sustainable Energy for All Initiative (SE4All, 2017). Growth in energy consumption has been identified as correlating with economic growth, for developed as well as developing countries (Cook, 2011; Ozturk, 2010; Wolde-Rufael, 2006). Apart from benefits associated with economic growth, access to electricity has also been identified as having positive impacts on education and health (Independent Evaluation Group, 2008; Kanagawa & Nakata, 2008).

Productive use of electricity (e.g. electricity used for income generating activities) is considered an important way of successfully linking electrification and development (Cook, 2011; Mulder & Tembe, 2008). The creation and modernisation of such activities makes access to reliable and affordable electricity an important precondition of long-term economic growth (Shyu, 2014). Several activities found in rural villages have the potential to be made more efficient by introducing electricity, such as milling, carpentry and increased opening hours for shops. Access to electricity can also lead to the creation of new businesses such as welding, internet cafés, bars selling cold drinks, electrical equipment and battery charging stations.

Historically, improved access to electricity in developing countries has been mostly through grid extension, with recent increased interest in small off-grid systems such as solar home systems (SHSs) and mini-grids. Grid extension has led to a focus on communities close to the grid or larger urban areas, excluding a large section of the population living in inaccessible rural areas (Ahlborg & Hammar, 2014; Díaz, Arias, Peña, & Sandoval, 2010; IEA, 2015; Tenenbaum, Greacen, Siyambalapitya, & Knuckles, 2014; Urpelainen, 2014). Off-grid systems provide an alternative in rural areas and are considered necessary in order to meet current electricity access goals (Tenenbaum et al., 2014). SHSs are relatively cheap but do not have the capacity to sustain many productive uses, which limit their impact on economic development (Azimoh, Klintenberg, Wallin, Karlsson, & Mbohwa, 2016). Mini-grids are large enough to support productive use activities. They are defined as small, independent electricity generation and distribution systems, supplying from a hundred to a few thousand customers.

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https://doi.org/10.1016/j.esd.2018.01.009

One of the major challenges relating to the dissemination of mini-grids is their poor economic performance, leading to an inability to cover operating and expansion costs (Barnes & Foley, 2004; Kirubi, Jacobson, Kammen, & Mills, 2009; Levin & Thomas, 2014; Schnitzer et al., 2014). Their ability to reach cost-recovery has been related to the mini-grid's capacity factor (Kirubi et al., 2009; Sarangi et al., 2014). A mini-grid's capacity factor is the ratio between maximum possible electricity generation and actual generation of electricity. To utilize a mini-grid efficiently, the capacity factor should be as high as possible. To maximize it, generation needs to be matched to current electricity consumption and be appropriately adapted to handle future changes. Thus, both short-term variations (such as daily load profiles) as well as long-term developments need to be sufficiently known.

Even though long-term developments in electricity and overall energy consumption in recently electrified areas very from case to case, the trend seems to indicate an overall increase in consumption over time. Pereira, Freitas, and da Silva (2010) analysed the long-term behaviour of 23,000 rural properties in Brazil and found that in four years there was a large increase in overall energy consumption amongst electrified properties. Díaz et al. (2010) found similar tendencies when they investigated the total system electricity demand of 16 sites in the Jujuy province, Argentina over seven years. These studies investigated long-term developments of total demand, but as Palma-Behnke et al. (2013) and Mandelli, Brivio, Colombo, and Merlo (2016) found, the daily demand variations in mini-grids are also important, especially for mini-grids relying on a large share of renewable energy sources.

Access to reliable, high-resolution data on electricity consumption in developing countries is sparse (Cross & Gaunt, 2003; Nfah, Ngundam, Vandenbergh, & Schmid, 2008). Due to the data scarcity, several studies have relied on alternative data sources or methods. Sen and Bhattacharyya (2014) found most studies did not consider measured load profiles when conducting technology assessments of mini-grids based on renewable energy sources. Instead, they used synthesized hourly load profiles based on collected appliance data. Boait, Advani, and Gammon (2015) analysed daily demand profiles for off-grid electrification in developing countries, using a similar method. A result of using data on appliance power rating and usage data is that the demand profiles have an hourly resolution. This means they may omit the impact of rapid changes, such as peak demand arising from the switching appliances on and off. Moreover, appliance data collected via interviews and/or questionnaires suffers from uncertainty in terms of usage patterns and power ratings. Blodgett, Dauenhauer, Louie, and Kickham (2017) investigated the accuracy of electricity assessments from appliance-specific data for small micro-grids (1.5–5.6 kW) and found large discrepancies when compared to measured electricity consumption. In an study of load profiles constructed from appliance data obtained from interviews, Hartvigsson, Ehnberg, Ahlgren, and Molander (2015) found discrepancies when compared with actual measurements.

Having access to accurate estimates of load profiles is important if high capacity factors are to be achieved and for successful implementation of mini-grid projects (Sarangi et al., 2014). If generation capacity is over-dimensioned, mini-grids risk suffering from poor economic performance. Similarly, if generation capacity is under-dimensioned, then technical functionality can be reduced, with negative effects for the operator. A lack of accurate data on load profiles has been identified in the literature. Cross & Gaunt, 2003 developed a residential load model for rural South Africa and identified a lack of data as the greatest problem in creating accurate models. Similarly, Wijaya & Tezuka, 2013 found a lack of electricity usage data to be the largest barrier to accurately studying household electricity consumption and thereby formulating efficient policies. A similar conclusion was drawn in a report by the World Bank. It concluded that access to high quality load data is necessary if appropriate technology investments is to be made in mini-grids (Terrado, Cabraal, & Mukherjee, 2008).

A common method of generating load profiles when measurements are unavailable is to use appliance-specific data such as power rating and usage (Blodgett et al., 2017; Boait et al., 2015; Mandelli, Merlo, & Colombo, 2016; Sen & Bhattacharyya, 2014). When obtained from interviews, this can provide a simple and resource-efficient method of estimating load profiles in already existing mini-grids. However, using load profiles from interviews affects the accuracy of the load profiles (Hartvigsson et al., 2015). The extent of the differences between load profiles constructed from appliance data and those from measurements is currently unknown. Consequently, the implications on dimensioning and operation of mini-grids arising from these differences is also unknown (Blum, Sryantoro Wakeling, & Schmidt, 2013; Cross & Gaunt, 2003; Hartvigsson et al., 2015). Previous work has been limited, either to describing the differences between the two methods (Hartvigsson et al., 2015) or to comparisons of energy consumption (Blodgett et al., 2017). It has not assessed any impact on mini-grid dimensioning and operations, or ways in which interview-based load profiles could be improved to give more accurate load assessments. Thus, the purpose of this paper is to assess the implications of using interview-based load profiles on mini-grid dimensioning and operation. Specifically, the paper aims to answer the following question.

- Do the differences between the load profiles based on appliance data collected through interviews and those based on measurements have implications for the dimensioning and operation of mini-grids?

The investigation involved comparing and analysing load profiles from appliance data collected from interviews with measurements using the same data-set as in (Hartvigsson et al., 2015). The measured data set is available for download and can be found under Complementary Material.

The paper is divided into five sections. First, the method is presented, including the two different data collection methods and load profile generation. This is followed by a description of the case to which our method is applied. Next, there is a presentation of load profiles and operator performance metrics based on high-resolution measured data and interview data. The results are followed by a Discussion section divided into three subsections focusing on: causes of differences, impacts on dimensioning and operation and improvements of the interview-based data. Conclusions are then drawn.

Method

To identify how load profiles from interviews can be improved and to investigate the impacts of interview-based load profiles compared to those determined from measurements, a set of load profiles was generated and measured in a rural Tanzanian village. The load profiles were generated and measured at three levels; 1) households, representing the major customers; 2) small and medium sized enterprises (SMEs) with large loads representing income-generating productive use; and 3) for the entire mini-grid. Although individual households consume relatively little electricity, they represent the majority of the customers and thus likely the majority of the load. SME customers with large loads are fewer by comparison, but their individual electricity consumption is considerably more, in terms of both energy and power. Hence, their individual impact is greater. Since not all customers (especially SMEs) use all their electric appliances on weekends, load profiles were collected and generated for weekdays and weekends (Sundays). Due to the different load characteristics between households and SMEs, the differences between interview-based load profiles and measured load profiles needs to be analysed separately for households and SMEs. Furthermore, to identify how well interview-based load profiles scale when compared to measurements, the load of the entire system also needs to be investigated.