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An assessment of unforeseen losses resulting from inappropriate use of solar home systems in South Africa

Chukwuma Leonard Azimoh *, Fredrik Wallin, Patrik Klintenberg, Björn Karlsson

Mälardalen University, School of Business, Society and Engineering, Box 883, SE-721 23Västerås, Sweden

HIGHLIGHTS

- Incorrect use of solar home system affects the energy output negatively.
- Optimization of operation of solar home system increases battery life in two fold.
- Incorrect use of solar home system increases the economics of owning it.
- User education is necessary for the sustainability of solar home system programs.

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ABSTRACT

One of the challenges to the sustainability of the Solar Home System (SHS) electrification program in South Africa is equipment theft. In response to this, communities susceptible to solar panel theft resort to mounting their panels flat on the ground so they can be looked after during the day and taken indoors at night for safe keeping. Other households use their security lights to illuminate their environment and provide security for pole and roof mounted solar panels at night. These actions have consequential effects on the performance of the SHS. Several studies have detected resentment from households regarding the low power quality from these systems. Most scientific contributions on the issue of low power from SHS have focused on the challenges based on the technical designs of the systems. The power losses due to the usage pattern of the system has not received much attention. This study therefore reports on the technical losses as a result of the deviation from the designed and installed specification of the system by the users in order to protect their systems. It also investigates the linkage between the technical and economic losses which affects the sustainability of SHS program. A case study was performed in Thlatlaganya village within Limpopo province in South Africa. Technical analysis using PVSYST solar software revealed that the energy output and performance of the battery is compromised as a result of these practices. Economic analysis indicates that the battery life and the economics of owning and operating SHS are affected negatively. The study recommends solutions to mitigate these losses, and proposes a cost effective way of optimizing the operation of SHS using a Bench-Rack system for mounting solar panels.

1. Introduction

The increasing cost of grid expansion and the externalities associated with fossil energy production have made renewable energy systems (RES) an irresistible choice for rural electrification programs (REP) in many developing countries. Evaluation of factors essential for a robust rural electrification program in Bangladesh and Fiji indicates that photovoltaic (PV) solar systems represents the most cost effective means of providing electricity to remote rural households [1]. Analysis of rural electrification programs in many villages in Nepal revealed that there is no convincing alternative to solar PV systems [2]. A review of RES production and utilization in Thailand indicates that a combination of renewable energy sources like PV, wind and diesel generators has good potential for implementing decentralized electricity for remote rural communities [3]. The appraisal of economic viability of different energy sources for rural electrification in Vietnam showed that the levelized cost of PV energy is lower than the alternative from the fossil grid [4]. SHS electrification program has been found to be a useful tool in reducing rural–urban migration in remote villages in rural Romania [5].

Assessment of rural electrification programs in South Africa showed that SHS is the most common technology used to increase

* Corresponding author.
E-mail address: leonard.azimoh@mdh.se (C.L. Azimoh).

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access to energy in the informal settlements due to its comparative advantage over other renewable energy sources [6]. The South African SHS program has been in place for more than a decade, resulting in many rural communities being equipped with solar based electricity systems [7]. However, the sustainability of the South African SHS program is under threat due to theft of solar panels and the resultant behavioral change of the households using the systems [8–10].

Theft of solar panels have resultant effects on the usage pattern of SHS as has been reported in numerous scientific publications. In India, an assessment of the Sundarbans project showed that most households have moved their solar panels from the optimal south facing position to more visible positions with less solar irradiation, to ensure that their equipment is not stolen [11]. In Papua New Guinea, equipment theft has compelled many households to return to solid fuels to meet their energy needs [9]. Panel robbery has become so common in rural Zimbabwe that most people now prefer to invest in other ventures, while some households have resorted to shielding their panels with steel bars, which causes shading of the panels [12]. Our investigation of South African experience with SHS theft revealed two emergent trends. One is the use of security lights to illuminate pole and roof mounted panels at night. The other is the habit of keeping solar panels under surveillance for 24 h of the day by most households, by placing them flat on the ground in front of their houses during the day to keep them within sight. At night, the panels are taken indoors for safe keeping.

These twin practices have been reported to have significant effects on the performance of SHS as a result of non-optimal use of the systems. A study conducted in Tehran shows that snow, pollution and dust affects the performance of solar panels, and that these effects are more severe at small tilt angles [13]. Performance analysis of PV systems show that the optimal tilt angle in the southern hemisphere is close to the latitude (θ) of the location [14]. The energy output of PV systems has been found to improve by placing them at an optimal tilt angle of ($\theta - 10$) in summer, and ($\theta + 10$) in winter [15]. Operating a PV thermal collector with reflectors at optimal positions improved both the electrical and thermal energy generated [16].

The two adaptive behaviors that we found have attendant effects on the economics of the SHS program, given by the reports from various studies in this field. A field study on the performance of lead-acid batteries associated with domestic PV lighting systems in Mexico, found that inappropriate use and limited maintenance practices emanating from lack of user education resulted in shorter battery life [17]. A study in Lundazi, Zambia indicates that overloading systems beyond the designed specification has a negative effect on the technical life of the battery [18]. In addition [19] showed that short battery life and high cost of replacement motivates the use of cheap batteries.

These adaptive behaviors are thus likely to affect the sustainability of the SHS program due to increased cost resulting from replacement of batteries. Many studies on the economics of PV systems have shown that they have economic advantages over other RES and fossil grid energy sources for rural electrification programs. After analyzing the techno-economic feasibility of grid connected PV systems using life cycle cost (LCC) [20] concluded that PV costs can be reduced with subsidies and tax exemptions. An evaluation of LCC of PV systems used in electrifying remote rural households in India showed that it is beneficial and suitable for long-term investment [21]. LCC model was used to determine the optimum relation between PV array size and the battery capacity [22]. The environment impact of fuels used for cooking in Ghana was investigated using conventional life cycle costing method [23]. Similarly, the influence of geographical location and the PV type on environment load and energy payback time (EPT) was evaluated using LCC [24]. An optimal sizing method based on genetic algorithm was used to achieve a required loss of load probability (LOLP) at a minimum annual life cycle cost (ALCC) [25].

The measures adopted by locals to protect their SHS are a reflection of lack of user education amongst the households in communities vulnerable to SHS theft in South Africa. Lack of user education is an indication of the alienation of the locals from projects. Following the assessment of lessons and experiences of rural electrification programs in Africa, [26] argued that SHS is a useful tool for rural development and electrification, but large scale diffusion of it demands an energy policy that supports partnership with local inhabitants. After analyzing 232 scientific articles, [27] recommended post-project plans that outlive subsidies in order to increase the likelihood of self-sufficiency and long term viability of projects in rural communities. Previous study have reported that a well articulate public–private partnership can deliver a cost effective energy service in rural areas [28]. The importance of partnering with the locals in rural electrification programs cannot be overemphasized, this situation captures the argument of [29] when it posits that, rural electrification programs can benefit greatly from the involvement of local communities or suffer because of its absence.

Reports from many scholarly article indicates that the low power capacity of SHS is a major challenge, and a veritable source of resentment against the system by the locals [30–32]. Publications such as [33] advocates for an increase in the capacity of SHS in order to improve the limited power capacity of the system. The use of sophisticated controllers to enhance performance of SHS has been achieved in a study like [34]. Bypassed diodes has been used to mitigate the effect of shading, thereby maintaining the power quality of a shaded solar panels [35]. Most of these solutions concentrated on the technical design of solar panels and its paraphernalia. Meanwhile, little attention has been given to the power losses that occurs on daily basis as a result of the usage pattern of the equipment. This study therefore investigates the technical and economic losses resulting from the divergence between the designed and the usage pattern of SHS in selected rural settlements in South Africa. It investigates the linkage between the technical losses and the resultant economic losses following the behavioral change of the users in response to solar panel theft. In addition, it recommends the right size of load suitable for the capacity of SHS currently in use in South Africa. Furthermore, it uses PVSYST solar software to investigate the right size of SHS that will meet the energy need of users in line with the adopted practices, and proposes a cost effective Bench Rack solar panel mounting device[1] for the optimization of operation of SHSs in developing countries.

2. The standard solar home system used in South Africa

The SHS used for the South African rural electrification project is a direct current (DC) system. It consists of a solar panel (either 50 W_P or 75 W_P), a 100 Ah, 12 V battery pack, battery safety fuse, and a charge controller. Electricity generation is achieved using solar panels, the battery stores the energy during the day and provides energy to the household load when the solar panel is not generating at night. The control unit controls the charging of the battery and provides a low voltage disconnect function against excess discharge of energy from the battery. Because the output power is low, it is used for appliances with low power consumption such as, lighting, DC television, radio, and cell phone charging (Fig. 1). The performance of the SHS is compromised when it is

[1] The Bench-Rack solar mounting system is designed to assist the poor households to achieve optimal use of solar home systems in the most cost effective manner. This is intended to overcome the habits of placing solar panels flat on the ground and the use of lights at nights to provide security for pole and roof mounted panels as a result of theft of solar panels.