Implementation of Solar Home Systems (SHS) in Vanuatu’s Tanna Island

Mengying Chen¹, Belinda Lam¹, Guanzhou Chen¹, Shuangshi Li¹, Xinyuan Du¹, Nicholas Lee¹, Sebastian Delaile and Richard Corkish¹

¹School of Photovoltaic and Renewable Energy Engineering, University of New South Wales, Sydney, 2052 Australia
E-mail: mengying.chen@unswalumni.com

Abstract

Due to the effect of Cyclone Pam in 2015, Vanuatu’s Tanna Island has suffered insufficiency of energy services because of the extensive damage to the electricity provision system, including to stand-alone photovoltaic and hydropower systems for public and private purposes. A recovery operation has been implemented to improve the health services, education and living standard of the local people. Furthermore, a UNSW program for solar home systems (SHSs) was conducted, culminating in a visit in January 2017, following a previous solar program. This project consisted of three SHS implementations, one system repair, two fridge battery replacements, and a user guide in two of the national languages, English and Bislama. It involved visiting five villages: Lawiaru, Lamlu, Iaunanen, Imaki and Louun. However, during this and previous similar projects, the reliability of the inverters was a major consideration, providing a motivation for the avoidance of inverters in our simple SHSs. An economic consideration also motivates this discussion. In addition, many other issues, such as bypassing of charge controller, volcanic dust-caused shading, extreme weather effects, faulty and inadequate wiring and battery cases, and system overload, have been found. This study therefore reports on the systems’ design and implementation and reveals common problems through the project. Recommendations for the avoidance of inverters in our simple systems are provided. Some relevant faults on the system have been put forward as both a warning and a guide to other students in future solar program endeavours.

1. Introduction

About 20% of urban and 83% of rural households in Vanuatu do not have access to electricity (IRENA, 2015). This situation was exacerbated by the Cyclone Pam occurred in 2015. There are more than 80% of houses and buildings were partially or completely destroyed (Handmer & Iveson, 2017) and this led to around 75,000 people becoming homeless at that time (Connors, 2016). Due to the effect of cyclones, Tanna has suffered insufficiency of energy services because of the extensive damage to the electricity provision system. A rapid recovery effort is underway to improve the health services, education and living standard of local people. Solar home systems (SHSs), are one of the most valid solutions actualize electrification in remote areas, where national grids cannot reach, to offset the cost of imported fuels (Urme, 2009). In fact, a previous active program has been conducted by one of us with Xiaowei Shen in 2016, including a SHS installation in Ikuaramanu and a SHS improvement for Imaki dispensary, to avoid winter shading (Shen and Corkish, 2017). After a
sequence of successful solar system installation on Tanna Island in recent years, contact has been maintained with Tanna community leaders to follow up the condition of the island’s energy services. According to the feedback, electricity is required in many other places. Therefore, we organized a subsequent trip to visit Tanna Island in January 2017 with a group of nine. This project was supported by the School of Photovoltaic and Renewable Energy Engineering, UNSW and donors for the purpose of recovery and installation of reliable SHSs at other sites on the island.

Photovoltaic technology has been increasingly employed from the early 1980s. A great number of SHS installations in rural area have already been in routine operation (Lorenzo, 1997). However, as complex systems, photovoltaic systems occasionally fail. Neglecting the effects of those failures may lead to the downtime of the entire system and implicitly increase the maintenance costs. A large fraction of PV system failures is thought to be inverter related (Ristow, 2008). So, the reliability of inverters was a major consideration, leading to a discussion about the avoidance of inverter usage in SHSs. An economic consideration also motivates this discussion.

In this project, three reliable solar power systems have been designed and implemented in Lawiaru, Lamlu and Iaunanen dispensaries; one solar home system has been repaired in Louen; two fridge batteries have been replaced in Imaki and Iaunanen; and a user guide has been composed in English and Bislama, two of the national languages. This paper will demonstrate five case studies in regard to these SHSs and reveal the common problems through the implantation, including the reliability of the inverters and some common faults that were found in this project.

2. Approach

The most common applications of SHSs that can deliver electricity reliably and at a low cost are lighting and phone charging systems for schools and health centers, and vaccine refrigeration systems for dispensaries (Government of Vanuatu, 2014). Although the applications are in various patterns, the method of SHSSs’ design and establishment are quite similar. In order to ensure system’s reliability and efficiency, a site assessment is a priority by surveying the local sources, including irradiation, wind, shading, etc. Unfortunately, in this case, a planning site visit could not be taken due to long distance and financial reasons, increasing difficulties of system design. Therefore, the information could only be gathered from the communication with community leaders and internet searches. For example, the irradiance and temperature data were drawn from the National Aeronautics and Space Administration (NASA) database (NASA SSE, 2017). In addition, taking the system oversizing into account, load assessment adopted a compromise that is based on the capacity of PV array and battery bank, and village circumstances and relevant Vanuatu and Australian Standards (Utilities Regulatory Authority, 2016 and AS4509, 2010).

Figure 1 illustrates the system configuration. Energy produced from the PV array can be directly consumed or stored in batteries and used later, such as during nighttime and cloudy days (Gandini and De Almeida, 2017).
Components including PV modules, batteries, controllers and other related tools were either donated or purchased opportunistically from Australia or Vanuatu. These components were then shipped to Tanna so that the capital can be minimized. For high system efficiency, cable loss is limited to 5% between the array and the batteries and 5% cable loss between the batteries and any loads. The implementation was carried out after the prior system design, which was then modified as required according to the current circumstance in the village. The implementation task was distributed to two groups, working in parallel, in order to minimize the time. By site visiting and system installing, several issues that may reduce system reliability were found during site visits and feasible recommendations are put forward for future projects.

3. Five Solar Home System Optimization

Many villages on the Tanna Island are far away from the largest town, Lenakel, which serves as a major port of entry and to which the island’s grid is restricted. As a result, these villages experience inadequate access to supplies. Moreover, the road between villages was in terrible condition, due to the heavy rain and challenging terrain. This increases challenges to energy suppliers to remote villages. This trip included visits to five villages where are the electricity deficiency was critical.

3.1. Lawiaru lighting and phone charging system

Lawiaru village is located on the north part of Tanna Island, in the region of “Middle Bush”. Services delivered by the dispensary in Lawiaru village were restricted by the lack of electricity. Although there was a previous solar power supply connected with a lighting system, it was in a poor condition, with several missing components and other system faults. One common fault was load connections bypassing the low-voltage disconnect manager in the charge controller. The new SHS prevented this kind of fault. The dispensary comprises seven rooms and two bathrooms. A staff house is next to the dispensary. Considering the orientation of the dispensary building, with roof sections facing east and west, the PV module was mounted on the roof of north-south oriented staff house.

Due to poor intercommunication, the information in regard to a previous provision by the Government of Vanuatu of a complete set of new components to build a PV system had not been passed on to the team. The components have been remained unused for months due to the insufficient technical knowledge in the village community (Lam, 2017). Therefore, the system design was recalculated to incorporate the provided PV panel and battery bank. Given the limitation of the system capacity, two 11W LEDs and four 7W LEDs can be powered for 6 hours, and 4 mobile phones can be fully charged. System performance is presented as a
production of approximately 149kWh energy per year and about 3430kWh energy over the system lifetime of 25 years. The levelized cost of energy (LCOE) for Lawiaru solar power system is roughly 3.1AU$/kWh. Figure 2 shows the electrical schematic of the lighting and phone charging system of Lawiaru dispensary.

![Figure 2. Electrical Schematic](source)

### 3.2. Lamlu stand-alone PV system

An upgraded stand-alone PV system for the dispensary in Lamlu was completed and commissioned in 19, January 2017. A yearly energy of 268kWh was expected to be produced by the system, which was more than the daily energy requirement of loads, allowing expansion of loads in the future. The village of Lamlu is situated in the middle of Tanna Island, about 16.3km away from Lenakel. The presences of the primary school, church, and dispensary in Lamlu make it be the main village. Higher electricity demand was required urgently. However, one most challenge problem was that as there is an active volcano located 15 kilometers away from Lamlu. Accordingly, solar panels installed in Lamlu could be significantly degraded with dust covered the surface of the panels. Therefore, regular cleaning is essential to allow the optimized performance of the system. Before the installation of the new PV system, there were already two SAPS installed outside the dispensary. One of them was powering the vaccine refrigerator independently, and the other was supplying power to the dispensary for regular energy usage, while the new PV system provided electricity for additional loads, composing five LED lights, one clinical light with higher lighting power and two USB phone chargers. Figure 3 and Figure 4 demonstrate system schematic and load distribution in Lamlu dispensary. Based on the economic analysis, the LCOE throughout the 15-year lifetime of Lamlu stand-alone PV system is about 3.24 AU$/kWh (Chen, 2017).

![Figure 3. Electrical Schematic (source: Chen, 2017)](source)
3.3. **Louen upgraded lighting and phone charging system**

A previous solar power system in Louen School has been examined by Xinyuan Du and his team and committed a result which shows almost all major equipment had failed during the 8 years’ operation since its installation in 2008, partly due to addition of additional loads. The repair was conducted which involved replacing batteries, battery converters, mainstream cables and solar panels. Moreover, additional lights were required to provide luminance for a new building. Finally, the system has been upgraded to provide ten lights for six different classrooms and 3 charging ports for phones, with around annual 163kWh and $AU6677 in total (Du, 2017).
3.4. Iaunanen solar home system design

Iaunanen is located on the South Island of Tanna and about one hour’s drive from Lenakel. The Iaunanen system, like a small solar home system, has been designed to power five LED lights, one light with emission spectrum suitable for cyanosis detection, one LED light bar and one phone charger in the village dispensary. This system simply connected a 220W PV module with a 130Ah battery through a BlueSolar MPPT 75/15. The electricity provided to the loads either drew from the PV array or from the battery bank (Li, 2017). This energy supply system was expected to be more environmentally friendly, withstand the common hazardous circumstances and have a long lifecycle. Meanwhile, economic and safety factors were also been considered to achieve low cost and the safety of people and components. In terms of the implementation, this system has been estimated to have a lifetime of 15-20 years with 2-3 times replacements for batteries, so ease of maintenance has also been taken into account.

3.5. Solar powered vaccine refrigerator system design

In another sub-project, a solar-electricity provider should have been designed to power a DC vaccine refrigerator in Imaki village to consistently achieve the desired temperature of 2 to 8 degrees Celsius. The electricity supply from the standalone solar system was expected to supply power to the electronic unit that controls the compressor speed, rechargeable fan battery, motor fan, thermostat, and LED within the refrigerator. However, a duplicate standalone solar system was installed by another organization. It was reported that the vaccine refrigerator at Imaki was checked to be in good condition other than the compressor fan that was missing, reportedly removed by the maintenance contractor. Nevertheless, the major shade caused by a big banyan tree was the main reason for reduction of the system performance in the winter. Several vaccine refrigerator repair works have been conducted in other villages on the island of Tanna as well. A similar problem occurred in Lamlu where the wire that was connecting the fan to an electronic unit was disconnected due to corrosion. From the investigation, the vaccine refrigerators at Lowiaru and Iaunanen were working without problems but the refrigerators at Lamlu and Imaki would require an inspection and repair (Lee, 2017).

4. Major Faults In System Implementation

4.1. Inverter Reliability

In PV systems, inverters are the most vulnerable components and responsible for the majority of failures (Ristow et al., 2008). An investigation on a previous SHS that powered AC lights and phones through an inverter in Imaki village reveals that the electricity came from the inverter which supplied to the loads was unstable leading to the flickering of the light bulbs. It was noted on another UNSW trip in July 2017 that the inverter had now failed completely. It is planned to replace it as part of another project in January 2018. This breakdown not only interrupts the whole system but also causes enormous economic loss. Therefore, highly reliable components are required, which lead to the discussion about the potential avoidance of inverter usage in SHSs.

Most inverter failures are blamed on the aluminum electrolytic capacitors that are typically used in the DC bus. Although high-reliability capacitors may maximize the inverter reliability and minimize the failure rate, they are quite expensive and therefore not as viable (Ristow et
In addition, switching devices, such as MOSFET and IGBT, are other vulnerable parts that impact the inverter reliability, which is dominated by the temperature (Chan, Calleja & Martinez, 2006). In fact, many inverters, particularly small consumer inverters of the type used in SHSs are exposed to harsh environments (Ristow et al., 2008). The failure rate of the inverter related to capacitors and switching devices are increased under the high temperature and high humidity condition (Wang, 2014). Given the consideration of the extreme weather on Tanna Island, inverters are not reliable. Volcanic emission is another factor that influences the inverter and other components’ reliability. Cronin and Sharp reported that volcanic gases from Mt. Yasur are acidic. These acidic gases always combine with water to generate acidic rain that may corrode electronics (Cronin and Sharp, 2002). Volcanic dust also could trigger overheating shutdowns by blocking ventilation grills and jamming cooling fans (USGS, 2017).

Besides that, typical AC appliances, such as water heaters, microwave ovens, air conditioners or refrigerators, are not commonly used on Tanna Island. In contrast, those low power devices, such as LED lights, mobile phones, and laptop, which are commonly used by local inhabitants, can be satisfactorily powered using DC current (Chen, 2017). Moreover, the cost of the inverter is rather high and the AC high voltage has a potential safety hazard. Under a trade-off, even though inverters may allow more application utilization, it is recommended that inverters should be avoided in our simple SHSs on Tanna Island.

4.2. Other Faults

In addition, many other issues, such as bypassing of the charge controller, shading by volcanic dust, extreme weather effects, faulty and inadequate wiring and battery cases, and system overload, poor module ventilation, and partial shading have been found. In the case of Lawiaru, the previous solar power system bypassed the charge controller and obtained the electricity directly from the battery, which may result in the failure of the batteries. Shading, either caused by volcano dust or trees was another issue that should draw attention. This issue was serious in Ikuaramanu, Lamlu and Imaki villages. Therefore, regularly cleaning is more important and which should be managed to local inhabitants. Additionally, destruction of infrastructure due to the extreme weather effects, such as cyclones, has happened in many places on Tanna Island. However, it could be avoided by installing a detachable PV system by coupling the PV panels with MC4 connectors, and use of mounting hardware to allow easy detachment with Allen keys (Lee, 2017). Furthermore, the system at Louen featured wiring that was poorly connected and merely tied together, resulting in the lights not functioning properly. Protective casings for batteries were low quality or non-existent at various sites as well, which could lead to dangerous situations. Hence, a complete enclosure with a proper lid should be used to protect the battery from objects such as metal or water falling on top, and minimize corrosion. Moreover, overloading and short-circuiting the PV system by adding too many appliances was a common issue. These extension applications drained excessive energy from the battery bank and could lead to the decrease of the battery life expectancy or, even worse, fires, fatalities or property loss (Lam, 2017).

5. Project constraints

5.1. Time Constraint

The total project was conducted over one year, however, the installation work has only taken 18 days, including five SAPSs construction. This was first time for these students to conduct
installation work. Although the tasks were allocated into two groups, the time frame was still tight. Besides that, shipping was another reason resulted in a tight schedule. An unspecific date for the ship arrival can prevent tasks being carried out as the components and tools were loaded on the boat, leading to temporary shortages and inefficient use of the available time.

5.2. **Geographical Restrictions**

Tanna Island is about 2400 km from Sydney. It took approximately 4.5 hours by plane, including the flight from Sydney to Port Vila and the flight from Port Vila to Tanna. There was no direct airline from Sydney to Tanna airport, thereby increasing the total expenditure. The road to Lawiaru village was harsh. A long distance of the road was unpaved, graveled or even just earth surface. During the rainy seasons, people were struggling to pass along them by 4WD. Therefore, the information capture was also becoming more difficult so that the information about the condition of the village was incorrect, resulting in an unknown situation that the local government has already donated a set of new solar system components to Lawiaru dispensary in the past and the refrigerator maintenance company had already carried out some vaccine refrigerator work.

5.3. **Funding Limitation**

Funding limitation was another constraint. Even though some second-hand PV modules were donated, helping the project saving a lot of expense, the transport and shipping costs were high. Also, the supplies on the island were restricted, leading to the high prices for the materials on Tanna Island.

6. **Further direction**

After the accomplishment of the installation of solar home systems, electricity has been delivered to the local dispensaries and schools, helping inhabitants to achieve better services. However, the later inspection work has not been implemented due to time limitation. Further checking will be conducted on the next trip.

Moreover, there are a lot of social institutions like Lawiaru, Lamluc, Iaunanen, Imaki and Louen dispensaries aspiring to electricity. Therefore, field survey has been conducted during this trip so that future projects can be carried out smoothly.

Finally, as local inhabitants are lacking knowledge of SAPS, a basic education/training program has been launched in parallel with the PV installation program. A future task is to work out a user manual and deliver it to end-users. For instance, the user manual in the national language, currently in draft form, will illustrate the precaution about the battery bank and shading and other issues identified above.

7. **Conclusion**

The Vanuatu SHS projects were motivated by the electricity demand and a serious limitation in energy supply in the remote area on Tanna Island. The objective of design and installation a reliable solar power system to meet the basic electricity demand in Lawiaru, Lamluc, Iaunanen, Imaki and Louen dispensaries have made a great success.

During the implementation, many faults have been found and also have been prevented in our new SHSs. In addition, the avoidance of the inverter in our simple SHSs has been pointed out and recommended for further projects. Moreover, this paper also demonstrates the restriction
of the project that came from many aspects, including time constraints, geographical restrictions and funding limitations, which challenged the project. The value of site surveys in advance is another valuable lesson for all projects of similar nature.

The electricity provision delivers huge economic, environmental and social benefits in rural areas. With the electricity supply, the improvement of local infrastructure is present in medical services, living standard, education, and communication. However, constraints of SAPS are reflected in the load limitation and maintenance difficulties. Therefore, a further direction should focus on the training program for local habitant. As well as, the subsequent checking of the completed systems and field inspection for further projects are also encouraged.

References


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