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A comparative case study of remote area power supply systems using photovoltaic-battery vs thermoelectric-battery configuration

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Abstract

The paper presents a comparative study of two types of remote area power supply (RAPS) systems, which are the existing photovoltaic-based (PV) configuration and the proposed thermoelectric-based (TE) configuration. Both RAPS systems are solar-based power generators and sized according to Melbourne weather conditions (latitude 37.5° S). In this study, the RAPS system designs for both PV and TE have no backup generator and the batteries are the only device for electrical energy storage. Battery storage is used for storing solar energy during the available days for meeting the energy demand as required. The presented RAPS systems for this comparative study are PV/Battery and TE/Battery configurations. Generally, both PV and TE cells are solar-based power generating cells but they have different pre-conversion inputs. For electrical power generation, PV uses sunlight as input energy while the TE uses concentrated solar heat. The results show that the total setup cost for TE/Battery system is 66% higher than PV/Battery system under similar design requirements. Despite having higher setup cost, the TE/Battery system has the potential to harness both electrical and thermal energy for domestic purposes.

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Keywords: Energy conversion; cell efficiency gains; passive cooling; phase change material

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1. Introduction

Photovoltaic (PV) panels and batteries are commonly used in remote area power supply (RAPS) systems to provide off-grid power supply in rural areas where power grids are not accessible to these regions. This type of RAPS system is called PV/Battery configuration. In principle, PV panels convert the incoming solar radiation into useful electrical energy for domestic use and the reminding energy will be stored in the batteries for backup supply during unfavourable weather conditions like rainy and cloudy days. For a typically polycrystalline type PV panel, the solar-to-electrical conversion efficiency is about 13-18% [1] and the remaining solar energy will be converted into waste heat which needs to be dissipated to avoid panel heating. The negative effect of PV panel heating is the declination of solar-to-electrical conversion efficiency (-0.5% per ºC) [2]. Therefore, PV/Battery configuration is not an efficient RAPS system as the residual waste heat in the PV panel poses negative impacts on the lifespan and electrical performance of the PV panels.

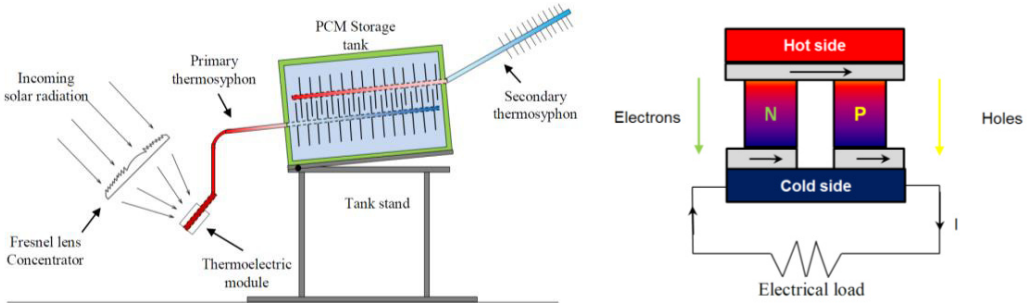

Fig. 1. CTEG-PCMTS system by Tan [3] (left) and schematic diagram of thermoelectric cell (right) [3].

In order to make RAPS system more effective and efficient, besides converting the incoming solar radiation into just electricity, the solar heat can be used for thermal conditioning purposes like space and water heating purposes for domestic applications. In order to have that cogeneration capability, Tan [3] has developed a concentrated thermoelectric generator coupled with phase change material thermal storage (CTEG-PCMTS) which can achieve dual energy production, electrical and thermal energy as illustrated in Fig. 1 (left). The cogeneration concept developed by utilising thermoelectric generator (TEG) for electricity generation and PCMTS for thermal storage. In general, TEG cell will generate electricity by providing a temperature gradient across the cell to achieve Seebeck effect shown in Fig. 1 (right). In his proposed system, the solar radiation was concentrated on the hot side of the TEG cells (solar heat) and the cold side was cooled by absorbing the waste heat into the phase change material thermal storage (PCMTS) to achieve thermoelectricity generation. The stored waste heat in the PCMTS can be then reused again for domestic space heating and hence reduce the electricity cost. For this RAPS comparative study and to be comparable to PV/Battery configuration, only batteries are integrated to the CTEG-PCMTS system to form the thermoelectric based RAPS with batteries (TE/Battery) configuration.

As mentioned earlier, both PV/Battery and TE/Battery are similar solar based power generators and uses comparable energy harvesting technology. Based on Tan's experimental prototype [3], the CTEG-PCMTS is a sustainable power generator as all components are passive devices, self-operable and capable to within high solar concentration ratios. In this comparative study, both RAPS systems are sized according to Melbourne weather conditions (latitude 37.5 ˚S).

2. Framework of comparative studies

In this comparative study, the RAPS system designs for both PV/Battery and TE/battery have no backup generator and the batteries required are sized for the month with the lowest solar insolation. Battery storage is the chosen electrical energy storage means for storing solar energy during the available days for meeting the energy