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ScienceDirect

Energy Procedia 135 (2017) 193–202

Energy Procedia

www.elsevier.com/locate/procedia

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

Thermal energy storage with phase change materials to increase the efficiency of solar photovoltaic modules

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Abstract

Thermal management is an essential design part for the application of solar photovoltaic (PV) modules, especially in hot regions in the Middle East. The operating temperature influences the efficiency as well as the reliability and lifespan of the modules. The purpose of this paper is to evaluate a new concept of passive thermal management by combining a phase change material (PCM) with metallic fibre structures in a PCM module to enable customised heat transfer properties. The module is mounted on the backside of the solar module. The system is assessed by numerical calculations, performed with the commercial finite-element software COMSOL Multiphysics. The results show that, compared to the case without PCM module, the peak temperature of the solar module for a daily cycle can be decreased by approximately 20 K by an adequate design with a limited usage of metallic structure. A parameter variation with different fibre structure properties, PCM, PCM module sizes and contact resistances was conducted and show the limits and main influence parameter on the system performance.

Peer-review under the responsibility of EUROSOLAR - The European Association for Renewable Energy.

Keywords: Latent Heat Thermal Energy Storage; Phase Change Material; Passive Thermal Management; Solar Energy; PV Performance

1. Introduction

The energy from solar radiation reaching the surface of the earth is many times higher than the global energy consumption. For the production of electric energy the photovoltaic (PV) effect can be used by applying solar cells

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Peer-review under the responsibility of EUROSOLAR - The European Association for Renewable Energy.
10.1016/j.egypro.2017.09.502

based on semiconductors. The application of solar modules, especially in regions with high solar irradiation (i. e. the Middle East), shows among others two challenges:

- Due to the conversion efficiency of the photovoltaic cells, just a part (for commercially available mono-crystalline silicon based cells typically between 15 to 17 %, referring to [1]) of the solar irradiation can be converted into electric energy. The residual energy is transformed into thermal energy leading to a temperature increase of the cell. Typically the conversion efficiency of the cells decreases with rising temperature. The coefficient for the power decrease of silicon based PV cells above 25 °C is between 0.4 - 0.65 %/K [2].
- At night the modules cool down and there is a risk that a part of the water vapour in the ambient air condensates at the surface of the solar module. The water encourages dust to stick on the solar module. The slurry builds up a layer on the module which forms a solid crust by drying during daytime. This also leads to an efficiency decrease.

To minimise the temperature increase during daytime the heat has to be dissipated to the surroundings or stored elsewhere. A review for the cooling methodologies of PV modules is given by [3]. The heat that can be dissipated is limited by the surface area and is not sufficient. As a consequence the heat has to be stored. One option thereby is to attach a storage unit to the backside of the solar module.

To store the heat during daytime a Phase Change Material (PCM) can be applied. Thereby the phase change between solid and liquid state is used to store a large amount of heat in a small temperature range at the phase change temperature. The high thermal capacity at a certain temperature offers the advantage of using the PCM as a "thermal fuse" to limit the temperature of the solar module. The heat, which is stored during daytime, shall be used to prevent the solar module from cooling down to low temperatures during the night. This represents a passive system for the thermal management of solar modules. Due to the passive operation no auxiliary energy consumption is needed. The thermal management of building integrated photovoltaics applying PCM without an additional heat conductive structure was investigated by [2], using various PCM and thicknesses to achieve a temperature reduction of 10 K. An evaluation for the performance enhancement of concentrating PV systems with usage of a PCM is conducted by [4]. A review is given by [5].

For an adequate functionality of the passive system the poor heat conductivity of the PCM has to be increased in order to enable a good heat transfer from the solar module. Additives like graphite can be used in the PCM to enhance the heat transfer properties, which was investigated by [6] for the cooling of PV modules. An alternative are metallic fin structures, evaluated by [7, 8].

Nomenclature

$c_{p,\mathrm{eff}}$	effective heat capacity of the PCM-fibre compound
$c_{p,\mathrm{F}}$	specific heat capacity of the fibre material
$c_{p,\mathrm{PCM}}$	specific heat capacity of the PCM
$\Delta h_{\mathrm{m,eff}}$	effective latent heat of the compound
$\Delta h_{\mathrm{m,PCM}}$	latent heat of the PCM
λ_{eff}	effective heat conductivity of the PCM-fibre compound
λ_{F}	heat conductivity of the fibre material
λ_{HF}	heat conductivity of the heat conductive film
λ_{PCM}	heat conductivity of the PCM
K	structural coefficient of the fibre structure
Ψ	porosity of the fibre structure
ρ_{eff}	effective density of the PCM-fibre compound
ρ_{F}	density of the fibre material
ρ_{PCM}	density of the PCM
t	thickness of the PCM module