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Photovoltaic module temperature stabilization with the use of phase change materials

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ABSTRACT

The worldwide growth of photovoltaics (PVs) has formed an exponential curve for more than four decades. During this period of time, PVs have evolved from a pure niche market of small-scale applications towards becoming a mainstream electricity source. The influence of temperature on the electrical parameters of crystalline silicon solar cells and solar modules is well described in the literature. In order to diminish these effects, it is useful to decrease the module temperature by removing the heat in a hybrid system that combines a PV module and thermal collector (T) into a photovoltaic–thermal (PV/T) system. Two types of PV/T systems are popular on the market: air cooled and water cooled. A relatively new solution is the use of phase change material (PCM) in order to pick up excess heat. PCMs absorb, store, and release large amounts of energy in the form of latent heat at constant temperature. Many innovative applications can be found for PCMs, which raise the efficiency of equipment, among other advantages. In the present paper, the experience of using PCMs for the stabilization of PV module temperature is presented. The results of these experiments are promising: for constant solar irradiance, the modified solar PV module (PV/PCM) heats up to a lower temperature than the unmodified PV module and the cheapest option is to apply 42–44 paraffin to the module without cooling, which made possible to lower the temperature of the module by 7 K. During the experiment, the lowered temperature was maintained for more than 5 h, allowing the PV module to work at a temperature close to the optimum one for the entire period of intense lighting.

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1. Introduction

In order to increase the efficiency of photovoltaic (PV) modules, it is useful to decrease the module temperature by removing the heat in a hybrid system that combines the PV module and thermal collector (T) into a photovoltaic-thermal (PV/T) system.

The advantages of using a hybrid system, especially one integrated with the building, are (Leenders et al., 2000): reduced production costs of one hybrid compared to the use of two different collectors, reduced roof area, reduced installation and mounting costs of the system, enhanced uniform architectural appearance and aesthetics, reduced operation temperature (PV cell temperature) and increased conversion efficiency as observed in the system described in Radziemska (2003).

The thermal efficiencies calculated from the theoretical model are about 55% for air-cooled systems and in the range of 45–65% for the water-cooled type (Sopian and et al., 1996; Bhargava et al., 1991).

The applications of phase change materials (PCMs) can be divided into two main groups: thermal protection or inertia and storage. The difference between these two substantial fields of applications relates to the thermal conductivity of the substance.

PCMs are proposed for use in PV modules to limit the cell temperature by absorbing heat during melting. Malvi et al. (2011) presented a model and simulation results for a combined photovoltaic - solar thermal (PV/ST) system that incorporates PCM.

Huang et al. (2006) presented an experimental evaluation of PCMs for thermal management of PV devices. For three different PV/PCM systems, using RT25, the temperature at the front surface of the PV/PCM system was maintained below 29 °C for 130 min with insolation of 750 W/m² and an ambient temperature of 23 °C.

Hasan et al. (2010) achieved maximum temperature reductions of the PV front surface of 18 K for 30 min with the use of capric-palmic acid and $CaCl_2$ and 10 K for 5 h under irradiation of 1000 W/m² with the use of $CaCl_2$.

Huang (Huang et al., 2004) developed a numerical PV/PCM model and validated it successfully by comparison with experi-

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ments. At insolation of 1000 W/m^2 and an ambient temperature of 20 °C, for a system with two fins using PCM with a melting temperature of 32 °C and depth of 20 mm, the temperature on the front surface was maintained below 36.4 °C for 80 min.

Gkouskos et al. announced their intention to perform several experiments in the future by varying the type of PCM and its thickness in order to investigate the effect of the thickness of the PCM layer (RT27) on the energy conversion efficiency of the system and to find the optimal PCM for the weather conditions of a typical Mediterranean region (Gkouskos et al., 2012).

Cellura et al. presented the results of a numerical simulation of the thermal behaviour of an integrated PV/PCM system and concluded than a lower temperature of a PV/PCM system leads to a rise in the value of the system's efficiency (Cellura et al., 2008).

Japs et al. (2013) proposed the modification of a single crystalline silicon PV module equipped with a conventional, commercially available PCM and another one with a new PCM compound featuring an increased thermal conductivity but lower heat storage capacity. Based on measurements of temperature development and daily electrical energy yield it was concluded that the higher heat storage capacity of conventional PCM leads to higher daily electrical energy yields and that higher thermal conductivity of the PCM leads to lower operating temperatures of the PV module (Japs et al., 2013).

Because for each 10 K increase in cell temperature above 298 K the power output decreases by about 0.4–0.6% and this will obviously depend on module design, it is therefore important to ensure excessive temperature is avoided as far as possible, for example by modification with phase change materials. The authors performed a number of experiments in different PV-PCM systems and analyzed the obtained results.

2. Characteristics of phase change materials

PCMs can be divided into three main groups: organic compounds (e.g., waxes, paraffins, fatty acids, alcohols), inorganic compounds (hydrated salts), and eutectic mixtures. These compounds have different phase change temperature ranges that determine their usability in specified applications (Huang et al., 2006).

Depending on the application, the PCMs should be selected based on their melting temperature, should have a large latent heat, should melt congruently with minimum subcooling, and should be chemically stable, inexpensive, nontoxic, and non-corrosive.

The result of a differential scanning calorimetry (DSC) experiment is a curve of heat flux versus temperature level or time which can be used to calculate the enthalpy of transitions ΔH by integrating the peak corresponding to a given transition (ISO 6946:2007, 2007):

$$\Delta H(T) = \int_{T_0}^{T} C_p(T) dT \tag{1}$$

where ΔH [kJ] is the enthalpy of transition, $C_p(T)$ $\left[\frac{kJ}{K}\right]$ is the heat capacity at constant pressure, and T [K] is the temperature level.

In practice, Eq. (1) is simplified to:

$$\Delta H = k \cdot A \tag{2}$$

where k is the so-called calorimetric constant, which can be determined by analyzing a well-characterized sample with known enthalpies of transition, and A is the surface area under the curve, which can be determined, for example, by graphic integration.

Most organic PCMs are non-corrosive and chemically stable, exhibit little or no subcooling, are compatible with most building materials, and have a high latent heat per unit weight and low vapour pressure. Most of the PCMs undergo large changes in volume (approx. 10%) during melting. This may cause high stresses on the heat exchanger walls. Inorganic compounds have a high latent heat per unit volume and high thermal conductivity and are non-flammable and inexpensive in comparison to organic compounds. However, they are corrosive to most metals and suffer from decomposition and subcooling, which can affect their phase-change properties (Farid et al., 2004). Insufficient long-term stability of the storage materials and containers is a problem that has led to insufficient use of latent heat stores. This poor stability is due to two factors: poor stability of the materials' properties due to thermal cycling or corrosion between the PCM and the container (Zalba et al., 2003).

A relevant aspect is the useful life of these systems and the number of cycles they can withstand without any degradation of their properties. Hadjieva et al. (1992) verified the lack of effect of the cycles on the properties of paraffin and paraffin mixtures. Also, Gibbs and Hasnain (1995) confirmed that neither contact with metals nor the cycles degrade the thermal behaviour of paraffin and that it therefore has excellent thermal stability.