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Temperature distribution of photovoltaic module based on finite element simulation

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Abstract

A three-dimension thermal model of typical polycrystalline photovoltaic (PV) module was performed in finite element software. Based on the model, the temperature distribution of the cell layer and module's thickness direction were analyzed and simulated. The effects of environmental conditions such as solar irradiance, wind speed, ambient temperature and adjacent cell interval on the temperature distribution of PV module were investigated. The temperature distribution curves showed that the solar cell layer possessed the highest temperature of 331.76 K near the solar cell center. The increasing of adjacent solar cell interval decreased PV module temperature. Wider adjacent cell interval is recommended considering the electrical power output of PV module. The results also showed that higher solar irradiance is helpful for the heat dissipation of PV module but results in higher temperature. The effect of wind speed on PV module is obvious when it increases from 0 to 1 m/s and higher wind speed is helpful for the improving of PV module electrical efficiency. Lower ambient temperature is helpful for both the heat dissipation and the improving of PV module electrical efficiency, and this effect was obvious especially under high solar irradiance and low wind speed.

Keywords: Photovoltaic module; Finite element; Simulation; Temperature distribution

1. Introduction

Photovoltaic technology converts solar energy into electricity directly. Various influencing factors on electronic (Zhou and Chen, 2009) and thermal properties of silicon solar cells have been studied. Operating temperature has a significant impact on the electrical efficiency of PV modules and the decrease of operating temperature leads to an increase of the module efficiency (Skoplaki and Palyvos, 2009). However, solar irradiance which is neither reflected by the top glass covered on the module nor converted into electricity is converted into heat and increases the module temperature. To reduce PV module temperature and take advantage of the heat energy simultaneously, various photovoltaic/thermal (PV/T) collectors using air or water as heat carrier were designed (Othman et al., 2013). Thermal optimization methods of high-concentration and flexible thin-film PV modules were obtained by CFD simulations (Chou et al., 2012; Ačanski et al., 2010). And the effects of solar irradiance and ambient temperature on the performance of PV modules were studied using numerical models (Usama Siddiqui et al., 2012).

In this work, a three-dimensional model was developed using finite element software to obtain the thermal characteristics of PV module and optimize its performance. Different with the simulation models which concentrated all absorbed energy on solar cells or ignore energy absorption

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Nomenclature

A	area (m^2)
d	distance to S point (mm)
G	solar irradiance ($W\,m^{-2}$)
h	convective heat transfer coefficient ($W\,m^{-2}\,K^{-1}$)
I	adjacent cell interval (mm)
L	electrical power output (W)
P	received solar irradiance ($W\,m^{-2}$)
Q	internal heat generation (W/m^3)
T	absolute temperature (K)
T_a	ambient temperature (K)
T_c	cell temperature (K)
t	distance to X–Y plane (mm)
v	wind speed (m/s)
V	volume (m^3)
ΔT	the difference between maximum cell temperature and ambient temperature (K)

Abbreviations

EVA	ethylvinylacetate
NOCT	nominal operating cell temperature
PV	photovoltaic
TPT	Tedlar/PET/Tedlar

Greek letters

β	the solar irradiance and temperature coefficients (K^{-1})
η	photovoltaic efficiency

Subscripts

c	cell
max	maximum
module	photovoltaic module
ref	reference
in	input
total	the whole PV module

of some materials, this model took solar energy absorption of all materials into consideration to close to the actual situation. Due to the temperature dependence of solar cell electrical efficiency, iterations were used to obtain the precise cell temperature after the initial assumption of solar cell electrical efficiency (Lee and Tay, 2012). It showed a good accuracy when comparing the obtained simulation results in this work with the experimental data (Tina and Abate, 2008), nominal operating cell temperature (NOCT) provided by manufactures and other simulation results (Lee and Tay, 2012). The effects of solar irradiance, ambient temperature, wind speed and especially the interval of adjacent solar cells on the temperature distribution of PV module were studied using finite element simulation.

2. Method and software

2.1. Finite element model

The three-dimension model which simulates the thermal transfer of in polycrystalline silicon photovoltaic module consists of five layers: glass, ethylvinylacetate (EVA), polycrystalline silicon solar cells, EVA and TPT (Tedlar/PET/Tedlar) backsheet layer from top to bottom respectively. The parameters of all layers are shown in Table 1. The solar cells are embedded in EVA and have a dimension of 125 mm by 125 mm. The interval of adjacent cells is 2 mm. The PV module model used in our paper contains only one solar cell and the boundary is the longitudinal-section exactly at the middle of the interval between two adjacent cells. Therefore, the whole dimension of the model is 127 mm by 127 mm. To simplify the model, interconnector and metal electrode on cell surface are not modeled. Compared with the whole PV module model, the simplified model reduces computational costs and effort greatly. The geometry of the model is shown in Fig. 1.

2.2. Thermal hypotheses

The temperature distribution of the PV module is obtained in finite element software, using the following simplified hypotheses:

- The model boundary is taken to be adiabatic, for the longitudinal-section area is very small and it is the symmetry plane of two adjacent cells.
- Thermophysical parameters of all material are presumed to be isotropic and independent of temperature.
- The reflectivity, transmissivity and absorptivity of all materials are considered significant to the analysis and taken to be unity.
- To close to the actual situation, the solar energy absorption of all materials in PV module is taken into consideration.
- Referring to the solar cell reference efficiency of 12.5% (Hegazy, 2000), the solar cell electrical efficiency at temperature of 298 K is now presumed to be 15%.
- The ambient temperature is postulated as equal on all sides of the model.
- Concerning the heat radiation exchange, the back and front of the PV module are taken to view the ground and sky respectively. The ground and sky temperature is assumed to be equal to the ambient temperature (Armstrong and Hurley, 2010; Schott, 1985).