Energy and Buildings 88 (2015) 100–109

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Performance of a PV module integrated with standalone building in hot arid areas as enhanced by surface cooling and cleaning

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ARTICLE INFO

Article history:
Received 3 September 2014
Received in revised form 3 December 2014
Accepted 7 December 2014
Available online 11 December 2014

Keywords:
Automatic cooling and cleaning system
Control circuit
PV module
Film of water
Bernoulli equation

ABSTRACT

This study investigated experimentally the performance due to automatic cooling and surface cleaning of Photovoltaic (PV) module installed on the roof of a building in hot arid area as compared with that of a module without cooling and cleaning. The module cooling is controlled automatically according to the rear side temperature via rejection of none-converted solar-energy to the ambient to keep the PV module surface temperature always close to the ambient temperature. In addition, this system controls the cleaning period of the module front surface. The results showed a decrease of about 45.5% and 39% in module temperature at front and rear faces, respectively. Consequently, the cooled and surface cleaned module has an efficiency of 11.7% against 9% for the module without cooling and cleaning. Moreover, the maximum output power produced by cooled and cleaned module is 89.4 W against 68.4 W for non-cooled and non-cleaned module.

1. Introduction

The performance of PV module is strongly dependent on its operating temperature. Most of the energy absorbed by the module is converted to heat which is normally lost [1]. In common, PV module converts only 4–17% of the incoming solar radiation into electricity. Thus, more than 50% of the incident solar energy is converted to heat and accordingly the temperature of PV module is increased. The increase in module temperature in turn decreases the electrical yield and efficiency of the module with a permanent structural damage of the module due to a prolonged period of thermal stress (also known as thermal degradation of the module) [2].

The efficiency of PV modules decreases remarkably if the array temperature exceeds the critical daily temperature. Thus, it is necessary to keep the modules' temperature under this limit. One of the ways for improving the system operation is covering the modules' surface with a thin film of water [3].

Many researchers have investigated and proposed various methods of optimizing the PV performance such as active and passive cooling methods. In addition much effort has been spent on the development of hybrid photovoltaic/thermal (PV/T) collector technology using air and water as the coolant [4,5].

The PV/T concept was therefore brought forward to simultaneously cool down the PV cells and make advanced utilization of the absorbed superfluous heat. Such integrated technology is becoming an important solution to yield more electricity and offset heating load freely in contemporary energy environment. The most common method for cooling PV is by naturally or mechanically ventilated air, which can be achieved through incorporating an air gap between the back surface of PV module and a thermal insulation layer added to the module, resulting in about 8% and 41% peak electrical and thermal efficiency, respectively [6].

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http://dx.doi.org/10.1016/j.enbuild.2014.12.012
0378-7788/

However, the heat removal effectiveness was relatively poor owing to the low thermodynamic attributions of air. The water-based PV/T technology, which enhanced solar electrical and thermal efficiency at 9.1% and 42%, respectively [6].

Touafek et al. [7] studied theoretically and experimentally a new configuration of the hybrid PV/T collector which extracts heat from the photovoltaic module for heating purpose. This configuration is composed of tube and sheet galvanized steel integrated into a prototype. The advantages of this hybrid collector are better heat absorption and lower production cost compared to other configurations of hybrids collectors.

Reflection of the sun's irradiance typically reduces the electrical yield of PV modules by 8–15%. Krauter [8] used a thin film of water running over the face of the PV module to reduce the reflection of the sun's irradiance. This results in 10.3% increase of the electrical yield over the day.

The idea of adopting nanoparticles within the cooling fluid has been investigated by several researchers. Studies focused on the effect of nanoparticle on the thermo-physical properties of the fluid and to investigate the heat transport capability of nanofluids have been conducted [9]. Verma et al. [10] developed a non-lithographic nanostructuring process of the packaging glass surface instead of antireflective coatings on the glass in order to reduce reflection at the air/glass interface and achieve a self-cleaning property.

Alami [11] investigated the utilization of a passive evaporative cooling technique to control the temperature rise of PV modules that occurs due to the absorption of solar irradiance. The method involved incorporating a layer of synthetic clay to the back of the module and allowing a thin film of water to evaporate, and thus reducing the module temperature. The results proven the technical feasibility of the proposed approach by exhibiting a maximum increase of 19.4% to the output voltage and 19.1% to the output power. The incorporation of clay was very effective, cheap, silent and environmentally friendly. Chandrasekar et al. [2] developed a simple passive cooling system with cotton wick structures for standalone flat PV modules. The thermal and electrical performance of flat PV module with cooling system consisting of cotton wick structures in combination with water, Al_2O_3/water nanofluid and CuO/water nanofluid was studied. The results showed that maximum output power developed by PV module are found to be 47.5 W and 44.6 W with the use of wick structures in combination with water and nanofluid, respectively, while the maximum output power without cooling arrangement is around 41 W only. A maximum module efficiency of 10.4% is obtained with the use of wick structures in combination with water while the efficiency is 9% without cooling arrangement. The module efficiency is about 9.7% and 9.5% when cooling is provided with wick structures in combination with Al_2O_3/water and CuO/water nanofluid, respectively.

This concludes that bulk of the literature deals with (i) cooling of PV module by the method of extracting thermal energy for re-use as in applications, such as drying, space heating etc.,[12–19] and (ii) cooling of PV module with a stream of water or air, which uses additional energy to run the pump or blower [20–24].

The purpose of the present work is to develop a simple passive automatic cooling and cleaning system with stream of water for PV modules without employing pump or blower. A solenoid valve is used to control the flow of water (on/off) on the PV module to achieve the following objectives: (i) reduction of the module temperature (ii) automatic cleaning of the module from the dust and solid particles accumulation, especially in dusty areas (iii) controlling the quantity of used water to be at minimum (iv) maintaining uniform temperature across the module. Comparison of the thermal and electrical performance of the module being subjected to cooling and cleaning against that of a module without cooling and cleaning is also presented.

2. Materials and methods

2.1. Experimental setup

An experimental setup has been developed to study the effect of the proposed automatic cooling and cleaning system using a thin film of water (about 1 mm thickness) on the performance of photovoltaic (PV) modules. The proposed automatic cooling and cleaning system for PV modules has been installed as shown in Fig. 1 on the roof of the building of the Energy Resources Engineering (ERE) Department at E-JUST (Egypt-Japan University of Science and Technology)temporary campus in new Borg El-Arab city, Alexandria-Egypt. The experimental setup consists of the main parts as follows:

1. PV module
2. Source of water
3. Electric solenoid valve
4. Copper pipe with nozzles for spraying water over the module
5. Water tank with water level float valve
6. Control circuit which accommodates
   a. Main relay
   b. Data logger and control device (OM320)
   c. Auxiliary relay built in the data logger
   d. Control program

Two SF80-A thin film PV modules were used in this study. The reference one is located in upper side and the module with proposed cooling and cleaning system is located in lower side as shown in Fig. 1.

The electrical and physical characteristics of the PV modules used in this study are given in Table 1. The measurements were recorded during a clear day (10th of April 2014). Irradiance was measured by a pyranometer (see Fig. 2) at the same incidence plane of the modules: south at an elevation angle of 30. Ambient temperature was measured by K-type thermocouple. This is in addition to four K-type thermocouples installed on the two modules to measure the actual modules temperature. Two thermocouples are installed at the front face of the two modules. The other two are installed at the rear face of the two modules. The five K-type thermocouples were connected to the OM320 data logger and control whereas the data was reordered every hour during the period 06:00 AM to 06:00 PM. Wind speed was measured about 30 cm above the modules by Port Log weather station. Tracking of the "maximum power point" was done manually by utilizing the variation of an ohmic load and measuring output voltage and current.

Table 1
Electrical and physical characteristics of the PV modules.

Electrical specifications	
Company	Solar-frontier
Model	SF80-A
Maximum power (P_{max})	80 W
Maximum current (I_{mpp})	1.95 A
Maximum voltage (V_{mpp})	41.0 V
Short circuit current (I_{sc})	2.26 A
Open circuit voltage (V_{oc})	56.5 V
Max. solar insolation (irradiance)	1000 W/m^2
Spectrum	AM 1.5
Air temperature	25 °C
Physical specifications	
Cell type	Thin film
Dimensions	1,235 × 641 × 35 mm
Surface area (A)	0.7916 m^2
Weight	12.4 kg
Price	
Module price	$418.15