WIND ASSISTED PASSIVE THERMAL REGULATION SYSTEM FOR FLAT PV MODULES

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ABSTRACT

Higher operating temperatures of solar photovoltaic modules results in lower electrical power yield and conversion efficiency. Hence to counteract the drawback of reduced power output, an active or passive cooling system is often required for controlling the temperature of PV module during its operation. The objective of this article is to propose a new idea of using a wind assisted thermal regulation system. For this purpose, experimental investigations are performed on a 5 Wp flat PV module cooled by the wind assisted passive thermal regulation system in the location of Tiruchirappalli (78.6°E & 10.8°N), India. The thermal and electrical performances of flat PV module with wind assisted cooling system are also compared with the results of flat PV module without cooling system. The PV cell temperature is found to be reduced by 17% while the electrical yield is increased by 25% with the help of the proposed cooling system.

Key words: PV module, passive cooling, carburetor, cell temperature, venturi effect

INTRODUCTION

Non concentrated or flat solar photovoltaic (PV) systems are ideal for remote rural areas where other power sources are either impractical or unavailable to provide power for lighting, appliances and other applications. Further, the cost of extending a power line to provide electric service in remote locations may not be affordable. Hence under these circumstances, it is more cost effective to install a single stand alone PV system (Tiwari et al., 2011). In general, PV module converts only less than 20% of the incoming solar radiation into electricity. Thus more than 50% of the incident solar energy is converted as heat leading to undesirable short term and long term losses in PV modules. The increase in cell temperature, decreases in electrical power yield and efficiency of the module are some of the common problems that are referred as short term losses. On the other hand, long term loss is performance degradation and is dependent on environmental factors like temperature, water ingress and ultraviolet intensity (Ndiaye et al., 2014). The permanent structural damage caused by the development of thermal stress due to excessive heating of PV module and elevated operating temperature is known as thermal degradation of the module. Lifetime and reliability may be adversely affected due to hostile weather conditions, particularly high temperature (Kahoul et al. 2014).

The variation of energy conversion efficiency with temperature depends on type of module such as crystalline silicon or thin film. For a crystalline silicon module, the thumb rule is that the conversion efficiency decreases by 0.5% for every 1°C increase in the module operating temperature (Chow et al., 2010). However thin film type have lower negative temperature coefficient compared to crystalline silicon. For thin film technology, the drop in efficiency of PV modules made of amorphous silicon (a-Si), cadmium telluride (CdTe) and copper indium gallium selenide (CIGS) are in the order of 0.21%, 0.25% and 0.32-0.36% per °C rise in module temperature (Radziemska et al., 2002). Though the electricity yield and efficiency of PV module can be improved by cooling the solar cells with a fluid stream like air or water, a better option will be to re-use the heat energy extracted by the coolant. This led to the evolution of PV/T hybrid solar technology. Among these technologies, air and water based types are relatively mature technologies while refrigerant and heat-pipe based PV/T systems are still at exploratory level and prohibited from wide application (Zhang et al., 2012).

The thermal regulation technique used for solar PV modules can be classified as a passive technique or an active technique. Passive technique requires no direct application of electrical power whereas active technique requires external electrical power. The factors like minimum operating cost, high reliability due to minimum risk of operation and eco-friendliness favors the use of passive thermal regulation techniques for PV modules (Royne et al., 2005). From the literature review, it is learnt that a lot of research efforts has been made in the development of cooling system for PV module and hence it is an important research topic. For this purpose, a simple cooling system with automobile
carburetor is proposed in the present work. The automobile carburetor assisted cooling system take the advantage of flow of atmospheric wind to spray water on the top surface of flat PV modules. The cooling of the PV module is expected due to the flow moist air and water that is sprayed on the top surface due to carburetion action. The schematic of the mechanism of cooling is shown in Fig. 1. With this research motivation, experimental investigations are performed at Tiruchirappalli, India (78.6°E & 10.8°N) with a 5Wp PV module.

**Fig. 1 Schematic of principle of working of wind assisted PV cooling**

**Experimental setup of wind assisted thermal regulation system:** The experimental setup consists of a 5 Wp flat PV module, digital multi-meter for measuring the module power output in terms of current and voltage, temperature indicators, simple carburetor and a graduated reservoir. The PV modules used in the present work is made up of single crystalline silicon cells which are connected in series. A rheostat (100 Ω and 1.25 A) is used to vary the load during the measurements of IV characteristics. As the latitudes and longitude are 10.8° N and 78.6° E for the location of Tiruchirappalli, the PV module is mounted in north south direction sloping down towards south at a tilt of 15° with reference to the horizontal. This tilt angle also facilitate easy run-off of rain and dust. K type thermocouples are used for measuring the ambient and module temperature with a temperature indicator having a resolution of 0.1°C. The module temperature is measured by thermocouples that were fixed to the back side of the panel at five different locations (Fig. 2) while the ambient temperature is measured by a separate thermocouple placed in a ventilated and shaded enclosure at an approximate height of 1.5 m from the ground surface.

**Fig. 2 Schematic of the front side and rear side with the locations of thermocouples**

The wind speed is measured along the surface of the panel with the help of a digital anemometer (Lutron, Taiwan). The predominant wind direction for the location of Tiruchirappalli is north east (source: TEDA- Tamilnadu Energy Development Agency), hence carburetor is placed in north eastern direction at a distance of 100 mm from the panel surface. To facilitate easy flow of water from the water reservoir to the main fuel jet, the float in the fuel chamber, choke valve and the throttle valve in the carburetor are removed and the carburetor main fuel inlet line is connected to a small water reservoir. When air passes through the venturi, water is sucked into the airstream through a main fuel jet (sometimes referred as nozzle) located in the center of the venturi by venturi effect. The photographic view of the experimental PV modules is shown in Fig. 3. This experimental set up is installed on the roof top of the energy engineering laboratory at Anna University, BIT campus, Tiruchirappalli, India in such a way sufficient wind flow is ensured.
Experiments were conducted under clear sky and sunny conditions during the month of October 2013 from the morning to evening at 30 minutes interval. According to International Electrotechnical Commission (IEC 61215), the measurements will be more reliable and valid when the experiments were conducted on consecutive days. The average of the best results observed on consecutive 3 days from 6th to 8th of October 2013 is reported in this paper. Uncertainty analysis is carried out considering the possible errors in the measurement of temperature, voltage and current (Coleman and Steele, 1989). The calculations indicated that the uncertainties involved in the estimations are ±0.4% for temperature and ± 0.05% for output power.

RESULTS AND DISCUSSION

Temperatures that are measured at five different points on the back surface of the PV module are plotted in Fig. 4. The average of these temperatures is considered as the back side temperature of the photovoltaic module.

The temperature of the cells ($T_c$) within a PV module is slightly higher than the back-side temperature ($T_b$) by few degrees. The relationship between the two temperatures can be expressed as $T_c = T_b + \frac{G_T}{G_{ref}} \Delta T$, where $G_T$ and $G_{ref}$ is the solar radiation on PV module titled plane and reference solar radiation equal to 1000 W/m² (Skoplaki and Palyvos, 2009). Hence to estimate the cell temperature, solar radiation data on the module tilted surface ($G_T$) is measured using a solar pyranometer (Nunes Instruments, New Delhi, India) with an accuracy of ±5% on the full scale of 1800 W/m² (Fig. 5).

Thermal characteristics: The hourly variation of cell temperature and the ambient temperature along with the wind velocity is depicted in Fig. 6. It is observed that the ambient temperature varied from 28°C to a maximum of 37°C while the wind velocity varied from 2 to 7 m/s during the day of experimentation. It is also observed that the ambient temperature is higher with lower wind velocity. The cell temperature without cooling is higher than the ambient temperature throughout the day with a maximum module temperature of 46°C. The maximum cell temperature is reduced to about 38°C with the proposed cooling system. This corresponds to about 17.4 % in cell temperature. The effect of carburetion principle i.e., the sucking of water into the air stream by venturi effect is manifested by the fact that the cell temperature of the cooled panel is only slightly above (by about less than 1°C) than the ambient
temperature up to 12 noon during which higher wind velocities of more than 4 m/s are observed. However due to a sudden drop in wind velocity to a value of 2 m/s after 12 noon, the cell temperature remained at a temperature of 2.5°C higher than the ambient temperature. The flow of moist air over PV module surface and water drops that is dripped on the top surface of the PV module due to the carburetion action results in the necessary cooling of the PV module. The water consumption due to carburetion effect is measured by monitoring the drop in water level for every 30 minutes and is plotted in Fig. 7. The variation of wind speed is also depicted in Fig. 7 which indicates that the water consumption is higher with high wind speeds and vice versa.

**Electrical characteristics:** The PV and IV characteristics of the PV module for the cases of with and without cooling at solar noon are given in Fig. 8. It is inferred that electrical yield is maximum when the module is provided with cooling arrangement. A maximum electrical yield of 4 W is obtained with the use of wind assisted cooling system. However the maximum electrical yield is about 3.2 W only without cooling arrangement. This corresponds to a 25% increase in output power with cooling arrangement. This indicates that the cell temperature has a considerable effect on the output power of PV system. This is due to the fact that when the cell temperature increases, phonons are excited which impedes the uniform movement of electrons and this impedance reduces the efficiency of the module. In addition, it is also observed from measurements that the open circuit voltage increased significantly (0.14 V/°C) while the increase in short circuit current is only marginal (0.004 A/°C) when the PV module is cooled. It is also found that the fill factor defined as \( FF = \frac{I_m V_m}{I_{sc} V_{oc}} \) decreases substantially with temperature. Fill factor of the uncooled and cooled PV module is found to be 0.65 and 0.73 respectively. The reason for the decrease in fill factor with increase in temperature may be attributed to fact that the thermally excited electrons dominate the electrical properties of the semiconductor at elevated temperatures (Skoplaki and Palyvos, 2009).
CONCLUSIONS

A simple cost effective PV thermal regulating system that uses atmospheric wind and venturi effect is proposed. The proposed idea will be useful for rural and remote areas where high wind speeds prevail. The idea of fastening a small converging duct on the upstream side of the PV panel to create suction effect could be an option to implement the present idea to regulate the PV panel temperature in a more industrial and scientific manner. The following are the conclusions drawn from the experimental investigation on the proposed technique:

- The effect of carburetion principle i.e., the sucking of water into the air stream by venturi effect is manifested by the observations of reduced cell temperature. The cell temperature without cooling is higher than the ambient temperature throughout the day with a maximum cell temperature of 46°C. The maximum cell temperature is reduced to about 38°C with the proposed cooling system. This corresponds to about 17.4% in cell temperature.
- A maximum electrical yield of 4 W and 3.2 W is obtained with the use of wind assisted cooling system and without cooling system respectively. This corresponds to 25% increase in output power with cooling arrangement.

REFERENCES


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