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Improving the efficiency of photovoltaic (PV) panels by oil coating

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ABSTRACT

The objective of this research is to develop a new technique for improving the efficiency of Photovoltaic (PV) panels. This technique is done by coating the front surface of the PV panel by a fine layer of oil in order to increase the amount of light transmitted to the panel, and consequently its efficiency. Different types of oils are examined, including both mineral oils and natural oils. In case of mineral oils; vacuum pump oil (Labovac oil), engine oil (Mobil oil) and brake oil (Abro oil) are examined, while in case of natural oils; olive and sunflower oils are examined. An experimental setup has been developed to examine the performance of the PV panels as a function of oil coatings. The experimental setup consists of an artificial sun, the PV panel under investigation, a cooling system and a measuring system to measure the performance of the panel. It has been found that coating the PV panel with a fine layer of Labovac oil, ~1 mm thick, improves the efficiency of the PV panel by more than 20%, and this is due to the high transmissivity of the Labovac oil compared to other oils. However, the Labovac oil has a drawback which is overheating of the panel due to its high transmissivity. Coating of PV panels with a fine layer of Labovac oil should be done only in cold regions, in order to avoid the heating effect that can decrease the power output of PV panels.

1. Introduction

Alternative sources of energy, i.e. renewable energy, have become important and relevant in today's world, due to depletion of fossil fuels and emissions associated with the use of fossil fuels [1,2]. One of the most important renewable energies is solar energy. Solar energy can be transformed into a useful form of energy, i.e. electricity, using Photovoltaic (PV) panels. Several factors affect the efficiency of PV panels, such as temperature increase and overheating of the panel [3], dirt accumulation on the surface of the panel [4], and low absorption for solar radiation due to scattering of the sun rays. Several techniques were introduced previously to improve the efficiency of PV panels.

One of the main obstacles that face the operation of PV panels is overheating due to excessive solar radiation and high ambient temperatures. Overheating reduces the efficiency of the panels dramatically [5]. Cooling of the PV panel can be done by the hybrid Photovoltaic/Thermal (PV/T) system [6]. The main purpose of the PV/T system is to extract heat from the photovoltaic panel and lower its operating temperature, and that extracted heat is not wasted but used for other purposes in the thermal system, e.g. domestic heating. Extensive research has been carried out by many researchers [7–10] in designing and optimizing hybrid PV/T systems for its commercialization. Zondag et al. [11] analyzed several concepts of PV/Ts, and it is found that PV/T improves the performance of the PV panels and the power output, however, they are expensive compared to PV panels or solar thermal collectors alone. Moreover, PV/T systems are economically feasible in hot regions rather than cold ones such that there is excess heat to be removed.

Other techniques implemented to improve the power output of PV panels is solar tracking [12–15], in which an optical device is used to track the sun and rotate the panel in order to optimize the angle of incidence between the sun and the panel. A photovoltaic tracking system is a system that tracks the sun from sun rise till sun set for maximum energy gain. This technique proved to be beneficial in cold regions where the sun can be tracked without causing overheating or even burning of the PV panels [16]. However, solar tracking is expensive and complicated in its design especially if multiple axes tracking is used. Sharaf Eldin et al. [17] found that tracking the sun will not be feasible in hot countries due to overheating because of excessive exposure to solar irradiance. A developing approach that is used to overcome the problem of overheating of PV panels is splitting the solar spectrum [18–21] before it reaches the PV cell, such that the portion that is responsible for heating the panel is removed by the beam splitter and used for

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thermal applications, e.g. domestic heating, while the other part of the spectrum is used for electricity generation in a "spectrum-matched" PV cell. Such approach helps to decouple the portion of the solar spectrum that harms the performance of the PV panel and limits its operation. Another approach is used to improve the efficiency of PV panels, which is by modifying the surface characteristics of the PV panels by adding organic materials or polymers [22–24], and it has been found that this technique can improve the efficiency of the panels but modifying the surface is difficult to manufacture and sometimes not economically feasible.

The efficiency of PV panels can be also increased by coupling more incident light into the PV panel, and this can be done either by increasing the transmissivity of the front surface of the PV panel or by minimizing reflections using antireflection coatings (ARCs) [25]. ARCs are a considerable way to sufficiently harvest more solar energy into the panel, and it has grasped lots of attention recently [26] because of its inherent effect on the performance of PV panels. The objective of this research is to improve the efficiency of PV panels by coating the front surface of the PV panel by a fine layer of oil in order to increase the amount of light transmitted to the panel and, consequently, its efficiency. An experimental setup has been developed to examine the performance of the PV panels as a function of different oil coatings and the operating conditions, i.e. solar irradiance and panel temperature. The experimental setup and procedure is presented in the next section followed by the experimental results and discussion.

2. Experimental setup and experimental procedure

2.1. Experimental setup

An experimental setup has been developed in order to examine the performance of PV panels as a function of oil coating, solar irradiance and panel temperature. A schematic of the experimental setup is shown in Fig. 1 and a photo of the setup is presented in Fig. 2. The setup consists of a PV panel, artificial sun, temperature measuring system and an *I–V* characteristics measuring device.

An artificial sun is created using spot incandescent lamps of 250 W each. The relative irradiance of the incandescent lamps versus wavelength has been measured at [27] according to the standard method [28] and the result is presented in Fig. 3. The relative irradiance is calculated by dividing the irradiance (power per unit area) at each wavelength by the maximum irradiance obtained at the range of operation. It can be seen from Fig. 3 that the light spectrum of the incandescent lamps is divided into two parts. One part, which is from 400 nm to 760 nm, is in the visible range of the solar spectrum. The other part, which is from 760 nm to more than 1500 nm, is in the infrared range of the solar spectrum. The lighting power of the lamps can be varied by varying the supply voltage to the lamps using a variable A/C transformer, which is known as the VARIAC [29]. Tungsten incandescent lamps are inexpensive and generate a continuous spectrum of light that ranges from central ultraviolet through the visible and into the infrared wavelength regions. Tungsten lamps radiate weaker in the shorter wavelengths but stronger in the infrared portion [30]. The light output from a tungsten lamp is proportional to the third power of the input voltage [31], which consequently affects the temperature of the filament in a tungsten lamp. However, as the filament temperature increases, the light emission profile shifts to shorter wavelengths in a bell-shaped profile, so that as temperature approaches the limiting melting point of tungsten, the proportion of visible wavelengths emitted by the lamp increase substantially. Increasing the input voltage to the lamps improves the emission spectrum of the lamp such that it approaches the emission spectrum of sunlight, but it is limited by the melting temperature of the tungsten filament.

The incandescent lamps are installed on a variable height stand such that the distance between the lamps and the tested PV panel can be varied, as can be seen in Fig. 2. A Photovoltaic (PV) panel of 20 W_{peak} is used in the performed experiments, which is installed on a fixed height table. The PV panel is a mono-crystalline panel from Solar-Tech [32], and the main specifications of the panel are given in Table 1. The lighting power intensity, i.e. irradiance, at the PV panel surface can be adjusted by (i) varying the lighting power of the lamps via the input voltage to the lamps and (ii) by varying the distance between the lamps and the PV panel. The lighting intensity is equivalent to the solar irradiance, and it is measured using a pyranometer. The panel temperature is measured using four thermocouples, which are located at the top of the panel and in the center of the four quarters of the panel.

The power output from the PV panel is measured using an *I–V* characteristics measuring device, i.e. PVPM 2540C [33]. The *I–V* characteristic curve, maximum power point (MPP), short circuit current (I_{sc}) and open circuit voltage (V_{oc}) of the tested PV panel are measured, displayed and stored by the PVPM device, such that the data can be retrieved at any time required. The back side of the PV panel is cooled by cooling water via a cooling coil that is installed at the back of the panel, and that is done in order to maintain a constant surface temperature of 25 °C at the back of the panel. An independent cooling water circuit is used to supply the required cooling water. The mass flow rate of the cooling water is controlled by a flow controller based on the temperature of the back side of the panel, which is measured with an accuracy of ±1%.

2.2. Experimental procedure

The performance of the PV panel as a function of oil coatings is examined through two sets of experiments. The irradiance has been adjusted to 1058 W/m^2 in the first set of experiments, while in the second set of experiments the irradiance has been reduced to 675 W/m^2, in order to check the reproducibility of the results. The 1058 W/m^2 irradiance and 675 W/m^2 are the average irradiance over the PV panel. The irradiance has been adjusted to the desired value as explained in Section 2.1. The irradiance is kept at a constant value during both sets of experiments while leaving the temperature of the PV panel to rise during the performed experiment. The temperature of the panel has been left to increase from 25 °C to 75 °C and the performance of the panel is measured at every 5 °C increase in temperature. The PV panel is coated with a very fine layer of oil, approximately 1 mm thick, and the performance of the PV panel, i.e. the power output, is measured. Various types of oils are tested, such as mineral oils and natural oils. The following oils are examined in case of mineral oils; Labovac oil (vacuum pump oil), Mobil oil (engine oil), Abro oil (brake oil), while in case of natural oils; olive and sunflower oils are examined. The physical properties of the different types of oils tested are presented in Table 2.

Another experiment is performed in the real sun, in order to discern the influence of oil coatings on the performance of PV cells in real life application. Three identical 10 W_{peak} PV panels are tested in the sun at the same time, in which one of the panels is coated with Labovac oil, the other is coated with sunflower oil and the third one is not coated with any oil. The three panels are placed in the sun, and the power output from the panels, and the temperature of the panels are measured every 15 min, from 8 am to 3 pm. Specifications of the 10 W_{peak} panels are given in Table 1.

3. Experimental results and discussion

3.1. Artificial sun experiments

The power output from the 20 W_{peak} PV panel and the corresponding efficiencies as a function of the panel temperature and