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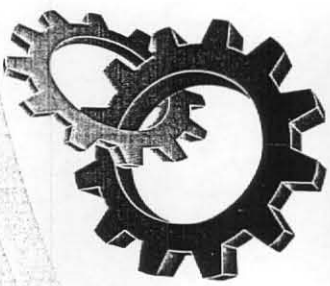
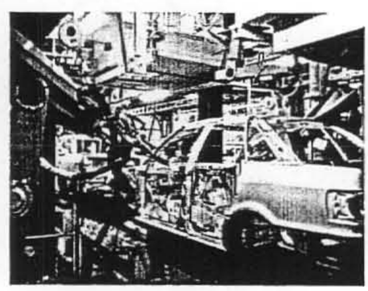
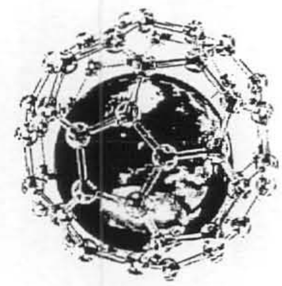

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Performance evaluation of PV Module using Water Filters and Infrared Reflective Glass Covers

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Abstract

The Photovoltaic (PV) system converts only a selected band (0.35µm to 0.82 µm) of solar radiation to electricity. The absorption of radiation outside this band leads to a temperature raise of PV module which affects its performance. Experiments were performed to prevent radiation outside the selected to reach the PV panel using water filtersand different types of infrared reflective pigments. The results of the experiments showed that the optimum water filter panel was the one with thickness of 10 mm. It led to about 4% improvement in the open circuit voltage of the module, and a significant reduction in the module's average operating temperature up to 21^{o}C. The optimum coated cover glass was 10 micron IRR glass cover which led to about 50% reduction in solar radiation, 22^{o}C reduction in the average temperature of the module, and 5.3% improvement in its open circuit voltage.

Keywords: *PV, water filters, infrared reflective pigments, infrared reflective glass cover.*

1.0 Introduction

Photovoltaic (PV) system is a device that converts solar radiation directly to electricity [1]. When solar cells receive the incident solar radiation, a complex interaction between the absorbed photons and the solar cell's structure occurs.This interaction is considered the main process of transformation of solar energy into electricity because it leads to generate so called electron-holes pairs[2]. However, the most effective semiconductors that can be used in manufacturing solar cells have band energies in the range of 1.0 – 1.8 eV. For crystalline silicon solar cells, which is used in this research, the band gap energy equal to 1.12 ev [3]. Photons that have energy equal or greater than the band gap energy of the crystalline solar cells are in the range of 0.35 to 0.82 µm. The rest of the solar radiation (below 0.35 and above 0.82 µm) will not be converted to electricity but converted to heat [2].An increase oftemperature of the solar cells above the desired value leads to a decrease the output power, efficiency, and the lifetime of the photovoltaic module[4].Maintaining the operating temperature of the photovoltaic system at low value was the main objective of many researches devoted by different research centers during the last decade. According to Teo et al. [5]water is considered one of the most significant way to extract heat from PV, because it has high heat capacity and thermal conductivity, so that PV/T system which is the combination between photovoltaic module or panel and thermal system (usually flat plate thermal collector) have been largely used and investigated during the last two years in order to cool down the photovoltaic systems and make them more efficient and competitive. The second common technique that was also largely tested and investigated using different types of coated glass covers in order to reflect the undesired parts of solar radiation and preventing them to reach the photovoltaic module.

In 1994, Beauchamp [6] used blue-red reflecting cover glasses to reduce the absorptance of infrared radiation in GaAs and amorphous solar cells. He found out that three percent of output power increased due to lowering the temperature of solar cells by using blue-red coated cover glasses. Sopian et al. [7] improved the thermal and the electrical efficiency of the thermal photovoltaic system by designing and testing a double pass air PV/T collector.Tripanagnostopoulos et al.[8] added thin flat metallic sheet (TFMS) in the middle of the air channel in the PV/T-air collector but its effect on the operating temperature of the photovoltaic cells was not significant.Russell et al.[9] conducted experiments on triple junction solar cell using Ultra violet reflective (UVR) and infrared reflective (IRR) coatings on glasses in order to reflect the ultraviolet and infrared radiation that are outside of the cell's response range but the efficiency gained was only about 0.5%. Rahman et al. [10] used two type of infrared reflective pigments and he found out that the efficiency of coated solar cells increased by 7.6% when compared to an uncoated cell.

In this study, three thicknesses (5mm, 10mm, and 20mm) of water filters were used to eliminate components of the radiation not contributing to electricity generation. Three types of infrared reflective pigments were also considered to study effects on PV module. Tests were conducted under different meteorological conditions and important parameters were measured to evaluate performance.

2.0 TheExperiment

Poly–crystalline photovoltaic module is used in order to study its performance with and without water filter panels and infrared reflective glass covers under Malaysian meteorological conditions.This type of photovoltaic module was chosen as it, nowadays, comprises about 90% of the photovoltaic market. In this study, efforts were devoted to find suitable means and ways to improve its output power, efficiency, and performance. However, it is tested in different times during different days to get the average of its performance under different meteorological conditions. Its open circuit voltage, short circuit current, top and bottom temperature and incident solar radiation were measured, monitored and recorded.However, in all experiments, there was about 10 cm distance between cover glass and / or water filter panel and the top surface of the photovoltaic module in order to measure and record the transmitted radiation from them (the radiation that penetrates through the cover glass or water filter panel and reach the module) ,as shown in the Figure 1.A Pyranometer was used to measure the incident solar radiation on the top surface of the cover glass or water filter panel (I Top) as well as the transmitted one (I Bottom). One of its limitations is that it does not measure the wavelength of the solar radiation. Digital Multi-meter was used to measure the open circuit voltage and short circuit current of the module. Thermocouples were used to measure the temperature of the top and bottom surface of the photovoltaic module (T Top and T Bottom), as shown in Figure 1.

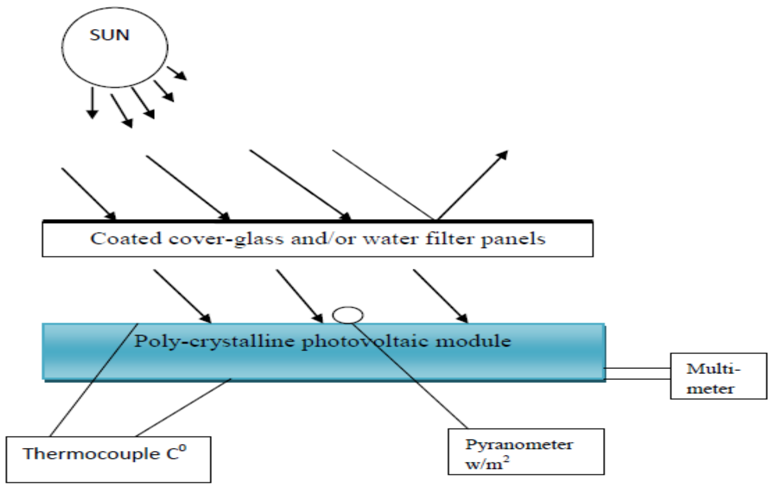

Figure 1: Schematic diagram of the experimental set-up

3.0 Resultsand Discussion

Photovoltaic only

The results of all experiments conducted on the PVM only showed that its top and bottom temperatures were increasing with time and irradiation until it reaches a high value (sometimes it reached more than 70 C^0), which clearly affected the open circuit voltage and , hence, the power output of the PV Module . Figures 2, 3 and 4 represent average temperature (Ttop + T bottom)/2) vs time, voltage vs time, incident radiation and current vs time, respectively.

Water Filters

The experimental results show asignificant reduction in the solar radiation due to 5mm water filter panels whichreached about 200 W/m^2 at an average incident radiation of 646 W/m^2, leading to about 20^{o}C reduction in the average temperature of its structure, as shown in Figure 2. Open circuit voltage of the module decreased with time, and it was improved by 2.3%, as shown in Figure 3. However, the reduction in radiation due to 10 mm water filter panel reached 270 W/m^2 at 852 W/m^2 average incident radiations, led to 21^{o}C reduction in the module's average temperature, and about 4% increment in its open circuit voltage, as shown in Figure 2 and 3. The results of the experiment also showed that 20 mm water filter panel absorbed and/or reflected about 300 W/m^2 of the incident solar radiation at about 1000 W/m^2. The reduction in radiation maintained the average temperature of the module around 44^{o}C, which equal to about 25^{o}C reductions in temperature. Therefore, about 3% improvement in the open circuit voltage was achieved, as shown in Figure 3.Short circuit current and radiation vs time for the optimum water filter is shown in Figure 4.

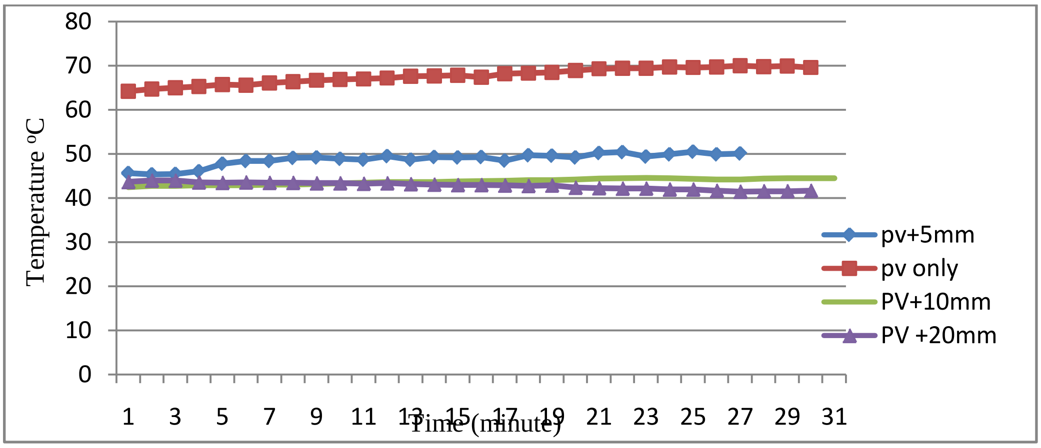

Figure 2: Comparison between Average Temperature for PVM Only and PVM with Different Thickness of Water Filter Panels

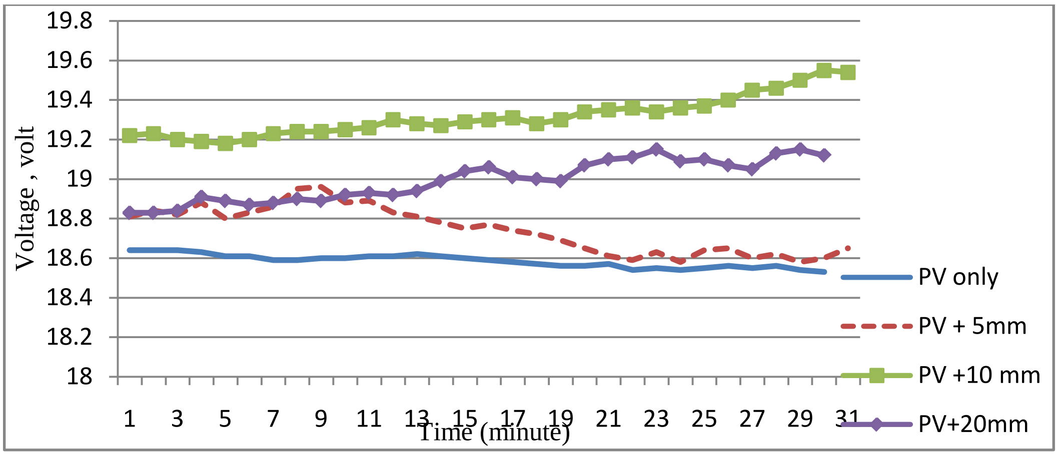

Figure 3: Comparison between Open Circuit Voltage for PVM Only and PVM with Different Thickness of Water Filter Panels

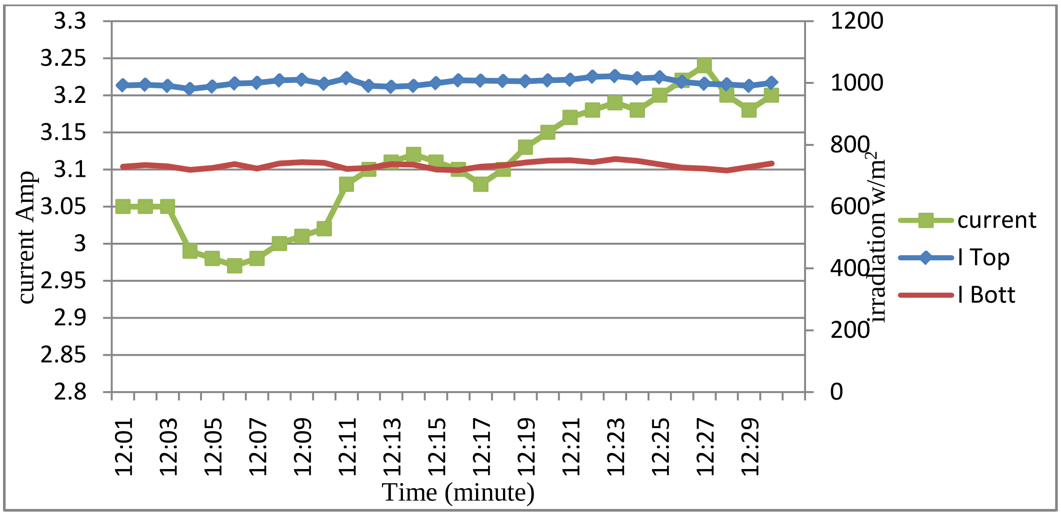

Figure 4: Top and Bottom Radiation and Current VS Time for 10 mm Water Filter Panel

Different Glass Covers

The performance of the photovoltaic module was investigated using a 3mm- transparent glass. The average enhancement obtained in the open circuit voltage was about 2.75 %, while the average enhancement in the short circuit current was about 9.6%, as shown in Figures5 and 6,respectively. The enhancement in both short circuit current and open circuit voltage led to about 26.4% increase in the output power, and 3% improvement in the efficiency of the PVM. The average reduction in the temperature sometime reached more than 12^{o}C due to the same uncoated glass cover, as shown in Figure 7.

The optimum coated cover glass was 10 micron IRR glass cover which led to 5.3% improvement in its open circuit voltage, and about 22^{o}C reduction in the average operating temperature of the module, as shown in Figure 5 and 7, respectively. The reduction in radiation due to10 micron IRR cover glass was very high (in some experiments was about 50%), because the proposed function of it (depending on the claim of the company and the reflectance curve vs wavelength of the pigment) is to eliminate all infrared radiation, which represent about 49% of the solar radiation, and preventing it to reach the photovoltaic module, so that this reduction in radiation was expected. Moreover, the experimental results for 20micron IRR glass cover showed that about 20^{o}C reduction in the average temperature of the module leading to about 2% improvement in the open circuit voltage, as shown in the same Figures. However, the reduction of radiation due to 30 and 40 micron IRR glass covers was too high; it sometimes reached 60% of the incident solar radiation, and about 20^{o}C reduction in the module's average temperature was achieved, but it caused no improvement in its open circuit voltage because it is expected that the interaction between the radiation and the pigment layer was very high.

Short circuit current of the module was negatively influenced by the significant reduction of the radiation due to the pigmented glass covers. It is strongly believed that the negative effect occurred due to the reflectance of the near infrared component of irradiation, so that the reflected and/or absorbed radiation due to IRR glass covers includes some amount of radiation that belongs to the spectral response range of the module. Furthermore, it is also believed that there was a thermal interaction between the incident photons and the pigment's particles making the photons that penetrate the pigment layer lose some of their energy which affects their ability to create electron-holes pairs. The thickness of the coating layer played an important role in influencing the amount of the transmitted radiation. The results related to the thickness of the infrared coating layer showed that the thickness should be less than 5 micron to avoid any possible interaction between the incident photons and the pigment layer.

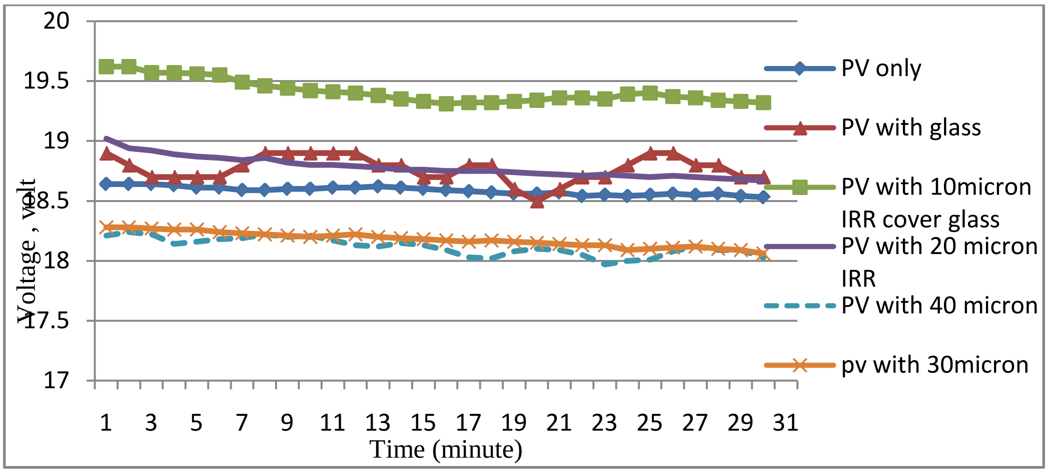

Figure 5: Comparison between Open Circuit Voltage for PV Only and PV with Different Cover Glass Used VS Time

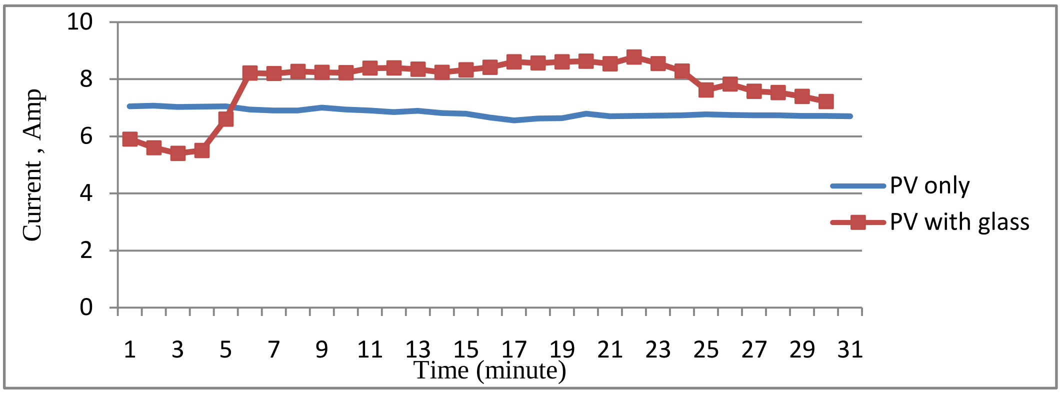

Figure 6: Comparison between Short Circuit Current for PV Only and PV with Uncoated Glass VS Time at Same Amount of Incident Radiation

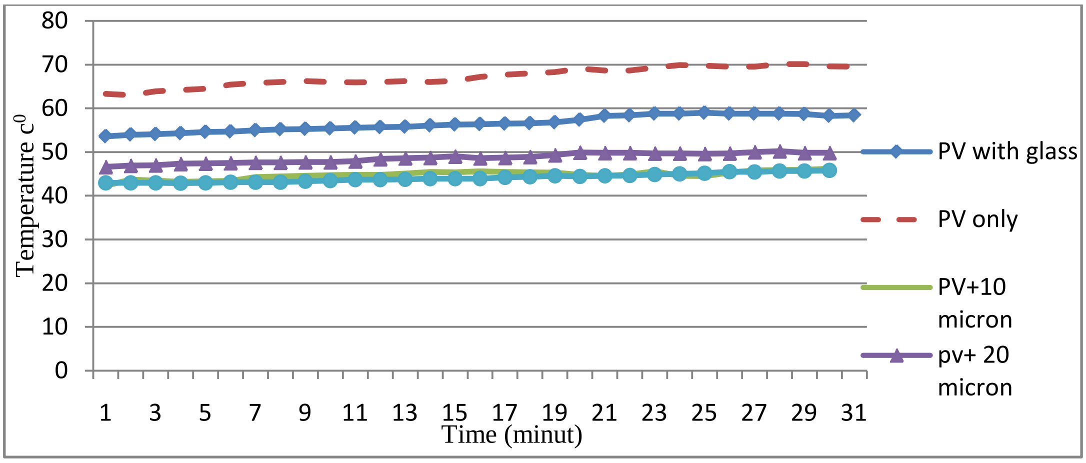

Figure 7: Average Temperature for PVM Only and PVM with different glass covers VS Time at Same Radiation

4.0 Conclusions

In this paper, the performance of a poly-crystalline photovoltaic modulewas evaluated with two different techniques: water filters and reflecting pigments. The results of the experiments revealed that the optimum water filter panel was 10 mm filter panel. It led to about 4% improvement in the open circuit voltage of the module, and about 21^{o}C reduction in the module's average temperature. The results also showed that 3mm uncoated glass cover led to about 12^{o}C reduction in the average temperature of the module, 2.75% improvement in its open circuit voltage, 9.6% enhancement in its short circuit current, and 3% in the efficiency. For other infrared reflective glass covers, the thickness of the pigment layer played a significant role in influencing the performance of the photovoltaic module as well as the reduction in the solar incident radiation, higher thickness led to higher reduction and vice versa. The optimum coated cover glass was 10 micron IRR glass cover which led to about 50% reduction in solar radiation, 22^{o}C reduction in the average temperature of the module, and 5.3% improvement in its open circuit voltage.

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