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The Performance of V-Trough Solar Concentrator Photovoltaic Systems at Varying Panel Surface Temperatures

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Abstract: *The photovoltaic (PV) panel performances are dependent upon many factors. A study was executed to ascertain the effect of a V-Trough Concentrator (VTC) to be engaged on a PV Panel in this research where the performance of PV panels are compared at different surface temperatures both back and front. The experiment was conducted using two similar rated monocrystalline PV panels. One of the PV panels was installed with a VTC while the other is without the VTC that served as Control for benchmark purposes. The optimum VTC selected is a 60° VTC. Both PV systems were built with a lower supporting mechanism and were placed to operate under similar operating and weather situations, while the PV panel surface temperature both front surface and back surface, Open Circuit Voltage (Voc), as well as Short-Circuit Current (Isc) readings are being recorded down at specific time. The theoretical output is determined and compared. This paper ends with a presentation of the results obtained in a study on the PV panel surfaces temperature in relation to its performance by PV system using a 60º VTC.*

Keywords: *Photovoltaic System, V-Trough, Surface Temperature*

I.INTRODUCTION

There has been a considerable increase in the awareness of sustainable development in the past decades around the world. Research and development activities are abundant related to harvesting energy from naturally renewable resources with one main objective – to reduce the dependence of commercial and domestic need on energy resources. Green energy is a form of energy that is available in abundance naturally as well as easily replenished or renewable. The green energy includes solar power, geothermal heat, rain and wind [1]. There are so many types renewable energy available but solar energy definitely constitute a promising source of energy and is highly appealing for its abundant quantity and availability. The solar irradiance from the sun can be harvested and converted to various forms of energy using multiple approaches including artificial photosynthesis, solar thermal collectors, and PV panels,. PV panels convert solar irradiance directly into electricity by means of semiconducting materials. Thus, the development and optimization of renewable energy harvesting methods become a very crucial factor in substituting the diminishing of fossil fuels in the same time meeting the increasing global energy demand.

The solar irradiance availability will affect the energy conversion output of a PV system. PV panel technologies that are readily available in the market usually are of conversion efficiency of 4% to 24% [2, 3, 4, 5]. The usage of a solar concentrator can further improve the performance as well as the output of a PV panel. The solar concentrator has a main function that is to redirect and concentrate solar irradiance from a larger area onto an area that is smaller. This upsurge of solar irradiance collected will have effect on the PV cells in energy conversion process. Solar concentrator can be applied to PV panels in numerous methods depending on the form of application needed. For Low Concentration PV systems, Compound Parabolic Concentrators and VTC are the two most commonly used designs [6]. For this research, VTC is chosen as the solar concentrator to be equipped with PV panel. The optimum design of a VTC must be able fulfil its function of redirecting and concentrating the solar irradiance whilst at the same time able to maintain a uniform solar irradiance by using a pre-determined and designed solar reflector with shortest slant height. Three parameters are important in designing a VTC. These parameters are properties of the reflectors, the concentration ratio, and the vertex angle [7]. A. Karthikeyan in 2016 performed a thermal analysis where in the experiment he conducted a comparison of performance between a flat plate collector and a VTC [8]. The author claimed that a 60° VTC provided the best heat capture rate for all VTC designs. Chong in 2012 [9] performed an optical analysis using a stationary VTC, and also proposed 60° VTC. The VTC in particular was manufactured and later tested so that identification of the thermal efficiency of solar water heater can be carried out.

II.METHODOLOGY

It was concluded that a 60° VTC or a vertex angle of 30° is the most appropriate design and with the appropriate angles to be used in this experiment. Chong [9] in his research paper shared a schematic diagram on the map of the sun light that is able to make sure that all incident rays collected by the VTC will make its way to the absorber plane using geometry optics and simple trigonometry. This schematic diagram is as illustrated in Figure 1.

The incident light is assumed to land on one end of the VTC at point A and it is perpendicular to the aperture plane indicated by Line DA. For optimum output, it is necessary that incident light to fall on at Point C on the other end of the absorber plane along the Line CB.

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This is to make sure all the perpendicular incident light would be reflected on the absorber plane. The Line CB is where the PV panel will be housed. Using the triangular properties involving the absorber plane width, reflected light, incident light, and, the design angle, θ can be calculated. It was determined to be at 60°. The vertex angle, ψ is related to design angle, θ as illustrated in the following equation:

$$\psi = 90° - \theta \quad \textbf{(1)}$$

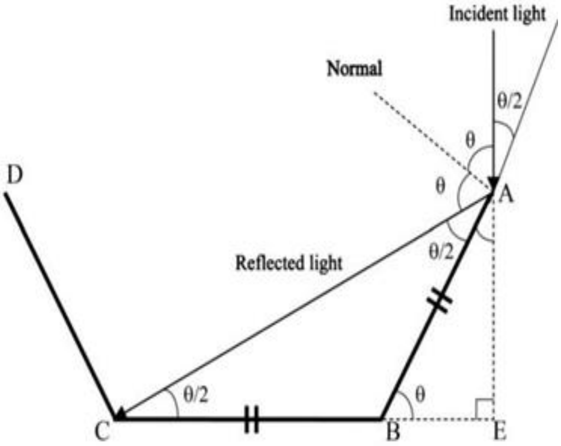

Fig. 1 V-Trough geometry optics Schematic Diagram [9]

For this project, a 60° VTC coupled with a 20W PV System prototype model is chosen and designed in a software environment using Solidworks Premium 2016 and further constructed and built as shown in Figure 2 and Figure 3. The 60°VTC is built to house a 20 W PV panel using a stainless steel (SS) with 2 mm thickness to house the PV panel in the middle. The SS VTC body comes with design with strengthened lower support mechanism designed using aluminum alloys to maintain the VTC at specific angle and hold the PV panel in place. Both sides of the VTC will house a mirror with the size similar to the PV panel. These mirrors are to increase the capture rate of available solar irradiances to maximum. Aluminum alloys were used as the lower support as aluminum absorbs very little amount of heat which would minimize the effect of the temperature on the monocrystalline PV panel.

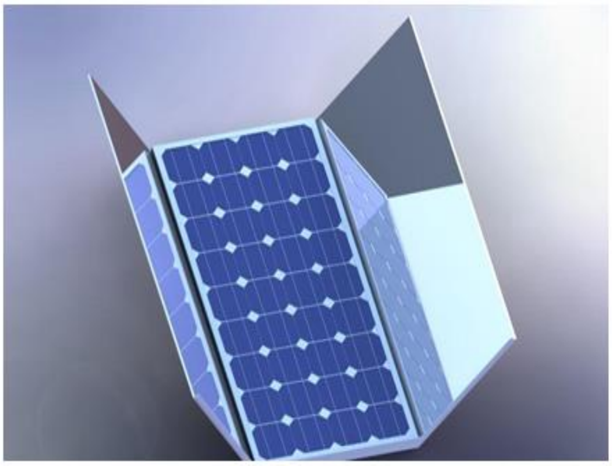

Fig. 2 VTC- PV Design in Solidworks Premium 2016

Fig. 3 Front (L) and side view (R) of the 60□ VTC with PV Panel [2]

Fig. 4 Front (L) and Side view (R) of Unmodified PV Panel [2]

Fig. 5 Non-contact infrared temperature gun (L) and Thermocouple (R)

The 60°VTC-20W PV system is setup side by side with an unmodified Standalone (S) PV System. The S-PV system is constructed as shown in Figure 4 and acts as a performance benchmark. In order to evaluate and identify the differences in the performance of systems, the Open-Circuit Voltage (Voc) and Short-Circuit Current (Isc) reading of both PV systems were taken from 10.00 am to 6.30 pm for Day 1 and 9.00 am to 4.30 pm for Day 2 at a 30-minutes interval. This experiment was conducted in an open environment where natural sunlight was abundant, with the same tilt angles and heading direction, in other words same operating conditions and configurations, to monitor the surface temperatures of the VTC-PV system and S-PV system.

The front surface temperature readings of the panels would be measured using an infrared, non-contact thermometer. The back surface temperature however will be measured using a thermocouple as illustrated in Figure 5. The output of both the systems would be monitored by taking readings of the Voc and Isc using digital voltmeter and multimeter as illustrated in Figure 6.

Fig. 6 Digital multimeter (L) and Voltmeter (R) used

III.RESULTS AND DISCUSSION

Throughout the data collection days, various data is collected and presented from Figure 7 to Figure 14. Figure 7 and Figure 8 illustrate the PV panel surface and back surface temperatures for both systems for Day 1 and Day 2. Based on the investigational data recorded for both the VTC-PV system and S-PV system, it is perceived that the temperature increases consistently in the morning until 1.00 pm after which the temperature started to drop to 2.00pm due to the slight cloudy weather in Day 1. The temperatures continue to increase again till 2.30 pm and increased again at 3.00 pm. After 3.00 pm the temperature consistently decreased until late evening. In this experiment, the panel back surface shown a noticeable higher temperature compared to front surface temperature. This is because an insulation material was placed on the thermocouple behind the PV panel. This step was initially a measure to prevent heat loss to surrounding however it had caused heat trapped condition instead.

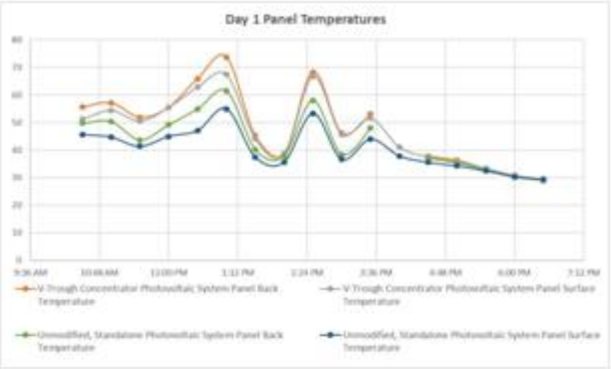

Fig. 7 Temperature Comparison of both PV Systems and Both Surfaces (Front and Back) for Day 1

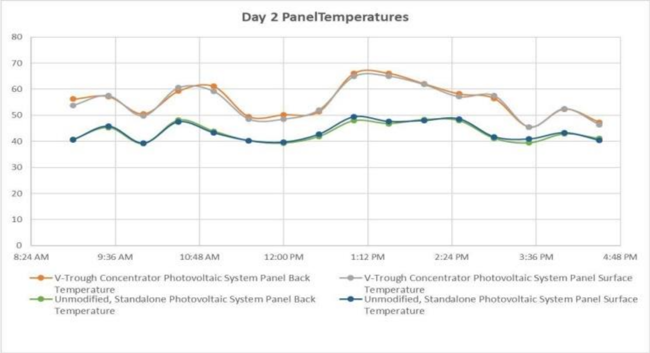

Fig. 8 Temperature Comparison of both PV Systems and Both Surfaces (Front and Back) for Day 2

In the data collection process in Day 2, the insulation material was removed. This has reduced the temperature difference in the font surface and back surface of respective PV panels. This is illustrated in Figure 8. The PV system with V-Trough concentrator reached peak temperature at 1.00 pm again and began to decrease after that .A similar pattern can be observed in the Standalone PV system. The peak temperature was reached at also 1.00 pm and decreased after that.

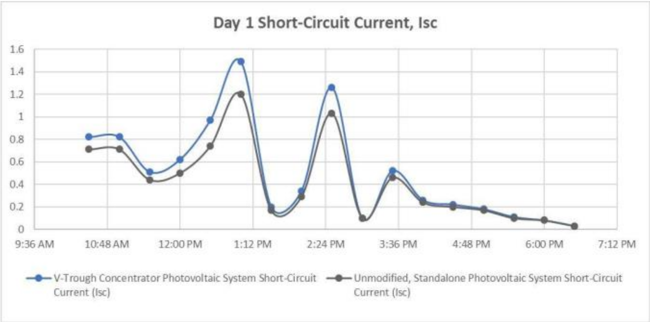

Fig. 9 Isc plot of VTC PV and S-PV system for Day 1

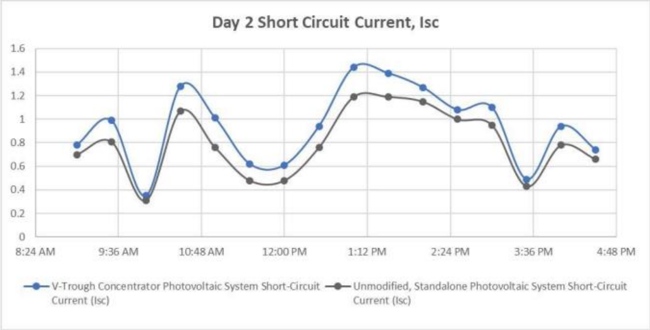

Fig. 10 Isc plot of VTC PV and S-PV system for Day 2

Figure 9 and Figure 10 illustrate Isc plot for both days data collection. From the data collected in Day 1 as shown in Figure 9, it can be detected that the VTC PV system was able to produce marginally higher magnitude of Isc compared to S-PV system. This is all the more obvious during sunny weather condition where a difference of higher magnitude was recorded in the current. At weather condition with low light levels such as cloudy situations, where the PV panels were producing currents of 0.1A and below, it was noticed that the current gap is no longer visible.

The changing weather conditions was the reason behind the fluctuations in the current value that resulted the rise and fall in values in the graph plotted.

For the experimental data obtained in Day 2, the data is as illustrated in Figure 10; there exist a rather constant amount of increment in Isc readings that was visible throughout the reading collection period. Similar to Day 1, the increment in Isc values of the VTC PV system over the standalone PV system reduced as the current output, or solar irradiance drops. The reductions in the value as portrayed in the graphs plotted were also due to the weather conditions that was changing all the time throughout the experimental period.

For data collected from both days, the maximum current recorded by the VTC-PV system was 1.49A while the SPV system was 1.2A. Both the S-PV and VTC-PV systems produced same lowest current 0.03A. Taking into account of all current values, the VTC-PV system in Day 1 had a 0.5A average reading whilst the average reading for the SPV system is 0.42A. For Day 2, the VTC-PV system had recorded an average current reading of 0.94A while the SPV system produced an average current reading of 0.8A.

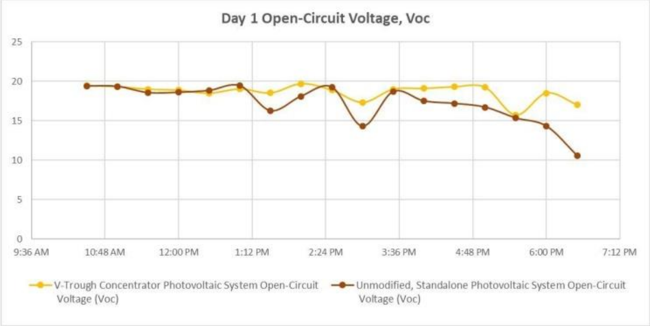

Fig. 11 Voc Plot for Day 1

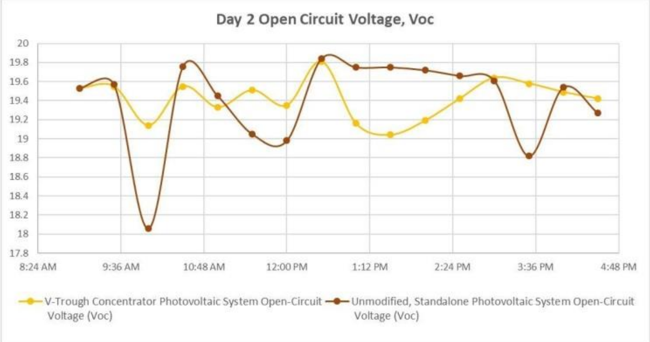

Fig. 12 Voc Plot for Day 2

Based on the data collected, in general, the VTC-PV system had a slight increment in Voc compared to S-PV system in Day 1.The readings recorded for VTC-PV remained relatively constant until 5.00 pm. For the S-PV system, the Voc has shown fluctuating values in the afternoon after 1.00 pm. For Day 2 data collection, S-PV system illustrated again much higher magnitude of fluctuations in Voc generation when compared to PV System with VTC.

The VTC- PV system recorded a peak voltage of 19.81 V while the S-PV system recorded peak value of 19.84 V. The lowest voltage recorded by the VTC-PV system was 15.74 V while the S-PV system was 10.58 V. Averaging all values of voltage obtained, the VTC-PV in Day 1 had a recorded average voltage of 18.62 V while the S-PV system average reading was 17.2 V. For Day 2, the VTC-PV produced average voltage reading of 19.42 V while the S-PV system had an average reading of 19.4 V.

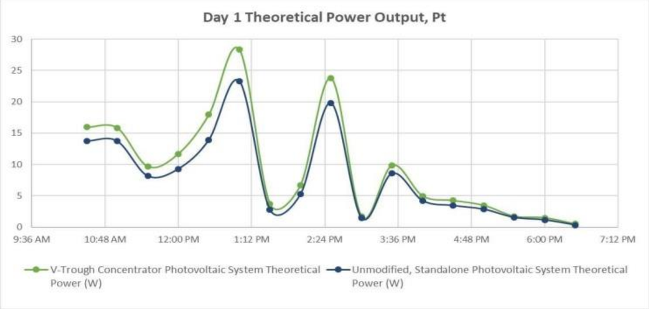

Fig. 13 Theoretical Power Output for Day 1

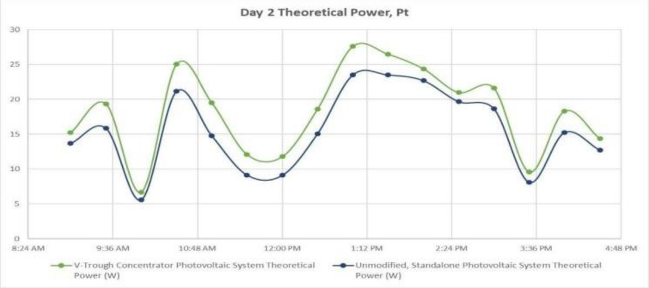

Fig. 14 Theoretical Power Output for Day

The VTC-PV and S-PV systems produced fluctuating values for Pt based on the data collected. The Pt value was determined by multiplying Voc with Isc. The VTC-PV system had achieved a maximum theoretical power output (Pt) reading of 28.3547W. The maximum Pt achieved by the S-PV system is lower at 23.316W. The VTC-PV system produced the lowest Pt at 0.5115W and the lowest power produced by the S-PV system is again lower value at 0.3174W. Averaging all Pt values recorded in the experiment, the VTC-PV collected results during Day 1 indicated it produced 9.51W on average, while for the S-PV system produced 7.86W average reading. In Day 2, the VTC-PV had produced an average power generation of 18.23W while the S-PV system had produced an average Pt with reading of 15.53W.

IV.CONCLUSION

This paper presented the design and installation of a VTC in PV system applications and proposed that it is feasible to be implemented in Malaysia. The performance of the stationary VTC that was designed, constructed and installed on a PV system is presented. The performance readings were Short-Circuit Current (Isc), Open-Circuit Voltage (Voc) was measured, and Theoretical Power (Pt) were calculated and determined respectively. These values were compared to readings obtained from a simple S-PV panel of similar specifications in the same operating conditions and configurations. In general, VTC-PV system produced on average a consistent increment 20% gain under varying weather throughout.

When comes to the temperature comparison of both PV systems, the reading from both surfaces of the VTC-PV system included, results collected indicated an average of 19.1% for Day 1 and 18.6% for Day 2 where they were higher than that of the S-PV system for Day 1 and Day 2 respectively. The highest temperature attained by the VTC-PV system is 80.2^{o}C. This temperature reading is below the manufacturer rated operating temperature for monocrystalline cells, which is 90°C. From all the results acquired, clearly all research objectives had been successfully achieved in this research. In conclusion, the experiment was a successful one. From the comparison of the results obtained, the average power output of a 60^o VTC-PV system is higher than an S-PV system. This indicated that a 60^o VTC is feasible solution to be installed onto a PV system in order to generate a generous amount of increase in PV cells efficiency.

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