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Performance Analysis of a Photovoltaic System under Different Configurations

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Abstract— Solar energy is used worldwide as energy can be harnessed directly from sunlight. Currently, the photovoltaic panel is considered as one of the fastest-growing renewable energy technologies that plays a major role in generating electricity. Sri Lanka receives a significant amount of solar radiation where Global Horizontal Irradiance fluctuates between 1247 kWh/m2 and 2106 kWh/m2 throughout the year. The power output generated by the PV panel depends on the irradiance received by the panel. When the irradiance increases, the power output of the panel also increases. However, as the solar irradiance increases, surface temperature of the PV panel also tends to increase. Higher surface temperatures cause degradation of the panel, and as a result, the lifetime of the same is reduced. Cooling of the PV panel can be used effectively to maintain the surface temperature at a desirable level while maintaining a higher power output. This study investigates the performance of a PV panel in terms of its power output under four different configurations at Ratmalana, Sri Lanka. It is observed that the power output increases substantially around 12 noon when reflectors are used along with the PV panel. However, this configuration records a higher temperature on the surface of the panel. It is observed that air cooling enables only a slight reduction of the panel surface temperature. When both air and water cooling are incorporated, panel surface temperature is reduced substantially while generating a higher power output. It is recommended that the conventional PV panel be used until 12 noon, and then switch over to the configuration that incorporates reflectors with air and water cooling in order to produce a maximum power output while maintaining lower surface temperatures of the panel that will increase the lifetime of the same as well.

***Keywords**: photovoltaic panel, power output, surface temperature, configuration, cooling*

I. INTRODUCTION

The global demand for energy is increasing annually due to the increasing world population and improved access to energy. Fossil fuels (Petroleum, Coal and Natural gas) are still the main source of energy in spite of many challenges and issues. Use of renewable energy has been emphasized in order to mitigate energy-related environmental issues and climate change (Ahmed et al. 2014). In the Sri Lankan context, solar energy has a key role to play compared to other sources of renewable energy. Solar energy will last for millions of years and as a result it will offer a better option for satisfying the future energy demand. In this backdrop, use of solar photovoltaic (PV) panels has increased substantially worldwide. As per current PV technology, the share of solar irradiation converted as productive energy is around 15% to 22% (Palaskar et al. 2014).

A solar cell is a basic p-n junction diode. Solar cells form a photoelectric cell, defined as a device whose electrical characteristics such as current, voltage, and resistance vary when exposed to light. When light reaches the p-n junction, the light photons can easily enter the junction, through a very thin p-type layer (Moharram et al. 2013). The light energy, in the form of photons, supplies sufficient energy to the junction to create a number of electron-hole pairs. The incident light breaks the thermal equilibrium of the junction (Rodrigues et al. 2011). The free electrons in the depletion region can quickly reach the n-type side of the junction. Similarly, the holes in the depletion can quickly access the p-type side of the junction. Once, the newly created free electrons reach the n-type side, they cannot further cross the junction because of potential barrier created in the junction (Arshad et al. 2014). Then the p-n junction behaves as a cell of a battery. The power output of a solar cell mainly depends on the surface area and is proportional to the intensity of sunlight striking the surface of the cell. Solar irradiance is a key phenomenon that governs the performance of a solar panel (Akbarzadeh and Wadowski, 2014). It is the amount of solar radiation that strike on a specific surface. This is mainly influenced by the orientation of the Sun with respect to the panel (tilt angle), geographical location, cloud cover and reflecting surfaces. When irradiance increases, more packets of photons strike the panel. When photons strike the solar cell, electrons tend to get released from the atoms in the semiconductor material. If electrical conductors are attached to the positive and negative terminals forming an electrical circuit, the free electrons can be captured in the form of an electric current (Tonui and Tripanagnostopoulos, 2007). The electrons collide with adjacent electrons and thus generate heat. This increases the temperature of the panel itself. Increase in temperature leads to increase in resistance to the current flow thereby reducing the power output and also causes degradation of the panel (Kiuth, 2008). It is found that, under concentrated solar radiation, the performance of solar cells is reduced by 50% when its temperature rises from 46 ^{0}C to 84 ^{0}C (Chaniotakis, 2001). Therefore, an efficient cooling system is essential in order to maximize solar cell's performance and to prevent the cell from getting degraded. Photovoltaic panels can be cooled actively or passively (Amelia and Irwan,2016). Active systems require an external power source while passive systems do not need an additional power source. The purpose of present work is to investigate the performance with respect to different configurations as follows.

II. METHODOLOGY AND APPROACH

The study was carried out at Ratmalana, Sri Lanka in July 2019 by using four different configurations as given below:

- Configuration 1: Without reflectors and cooling (with no modifications)
- Configuration 2: With reflectors
- Configuration 3: With reflectors and air cooling
- Configuration 4: With reflectors and by incorporating both air and water cooling

Each case was investigated at three tilt angles: 00, 200 and 300. Output voltage and current of the PV panel were measured to calculate the power output. Surface temperature of the PV panel, cloud cover and ambient temperature at the location were also measured. Data was recorded in every hour from 0800 hrs. to 1700 hrs. for three days for all panel configurations. The study used a polycrystalline silicon PV panel with a maximum rated power output of 500 W.

The PV panel surface was divided into 12 equal rectangular portions and the surface temperature of the panel was measured by taking the mid-point temperatures of each rectangular portion. A non-contact infrared thermometer was used for this purpose. Hourly solar irradiance (total amount of solar energy falling on unit area (MJ/m2)) was obtained with the kind support of the Department of Meteorology. Okta scale and a mercury-in-glass thermometer were attached to the PV system in order to measure the cloud cover and ambient temperature respectively. A cylindrical concave mirror was developed using strips of plane mirrors in order to function as a reflector in Configuration 2.

For Configuration 3, air cooling was introduced. In Configuration 4, both air and water cooling were incorporated. Cooling fins were fabricated using Aluminium sheets and were fixed to the bottom surface of the PV panel. For the process of water cooling, a water supply line was introduced by fixing half split 20 mm diameter PVC tubes to the bottom of the surface of the PV panel using thermal silicon sealant. Water was supplied by using gravity without the presence of any external power source. Data was collected for all four configurations under the same outdoor conditions.

III. RESULTS

Configuration 1: Without reflectors and cooling (with no modifications)

Table 1 presents key operating parameters for Configuration 1 at 00 tilt angle on hourly basis. Similar sets of data have been obtained for the tilt angles 200 and 300 as well. The power output of the PV panel was calculated on hourly basis. For further comparison of performance, graphical representation of results have been done in Figures 2 and 3.

Table 1: Key operating parameters for Configuration 1

Time (hour of the day)	Average Surface Temperature (⁰C)	Voltage (V)	Current (A)	Power Output (W)	Irradiance (W/m^2)
0800	28.4	17.2	1.1	18.9	202.8
0900	44.8	20.1	6.2	124.6	277.8
1000	55.4	20.8	7.8	162.2	569.4
1100	57.8	27.1	8.2	222.2	591.7
1200	59.4	28.4	8.2	232.9	783.3
1300	59.9	30.1	9.6	289.0	797.2
1400	55.2	30.0	8.9	267.0	755.6
1500	49.2	18.3	6.6	120.8	644.4
1600	46.7	17.2	6.2	106.6	500.0
1700	43.3	14.6	4.5	65.7	266.7

According to Table 1, it was observed that both voltage and current increased from 0800 hrs. to 1300 hrs. and subsequently reduced from there onwards until 1700 hrs. This is evident for all three tilt angles. Hence, the power output generated by the PV panel reached its maximum around 1300 hrs. as shown in Figure 3. This is mainly due to the maximum irradiance level that the PV panel received during this time of the day. Surface temperature of the solar panel also rises with the increase in irradiance level. It was observed that the increase of average temperature of the PV panel surface follows a similar trend to that of the power output.

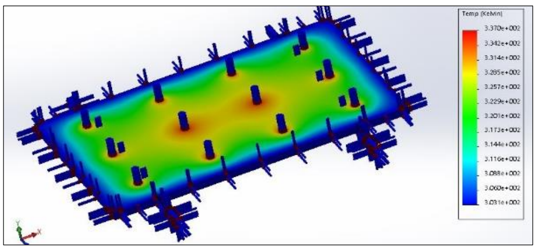

Figure 1. Average temperature distribution on the photovoltaic panel surface.

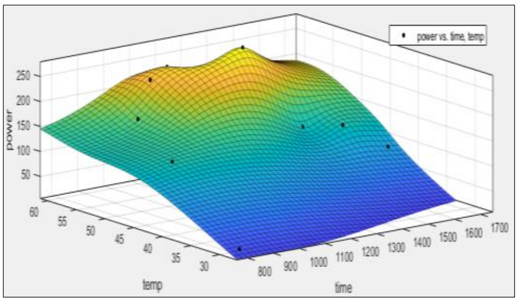

Figure 2. Variation of power output vs time and temperature at 00 tilt angle for Configuration 1

Figures 1 and Figure 2 illustrate the temperature distribution on the PV panel surface and variation of PV power output against time and temperature (3D) respectively.

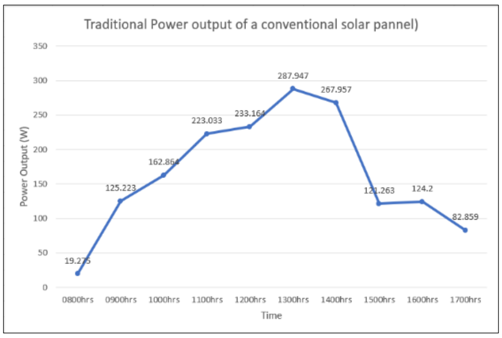

Figure 3. Power output of the photovoltaic panel: Configuration 1

Configuration 2: With reflectors

Table 2. Key operating parameters for Configuration 2

Time (hour of the day)	Average Surface Temperature (⁰C)	Voltage (V)	Current (A)	Power Output (W)	Irradiance (W/m^2)
0800	30.4	17.4	1.1	19.1	266.7
0900	37.8	18.3	3.3	60.4	500.0
1000	43.6	24.3	6.3	153.1	519.4
1100	46.7	25.1	7.0	175.7	775.0
1200	55.4	40.1	10.3	413.0	883.3
1300	61.0	42.8	10.9	466.5	969.4
1400	58.3	39.9	10.1	403.0	908.3
1500	56.8	35.8	9.2	329.4	694.4
1600	50.6	30.0	8.3	249.0	588.9
1700	47.6	28.2	7.0	197.4	318.3

As per Table 2, the voltage and current recorded a sudden increase between 1100 and 1200 hrs. This resulted in a large increment in power output as shown in Figure 4.

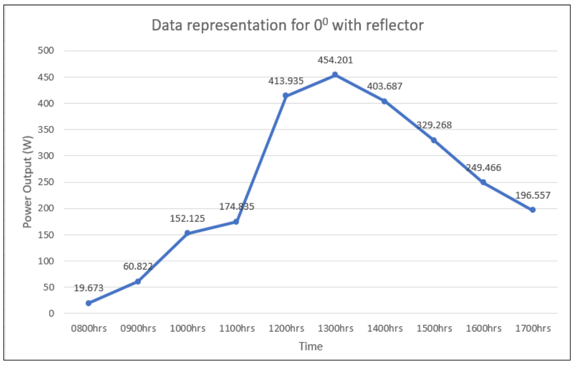

Figure 4. Power output vs. time in Configuration 2

The panel generates maximum power output around 1300 hrs. The impact of the reflector was not evident during the morning hours as the amount of solar radiation that was reflected on to the panel at that time was relatively less. As the amount of solar irradiation increased, the surface temperature of the panel also increased.

Configuration 3: With reflectors and air cooling

Table 3. Key operating parameters for the PV with reflector and air cooling (Configuration 3)

Time (hour of the day)	Average Surface Temperature (^{0}C)	Voltage (V)	Current (A)	Power Output (W)	Irradiance (W/m^2)
0800	28.3	17.7	1.0	17.7	258.3
0900	35.4	18.3	3.4	62.2	497.2
1000	40.7	24.4	6.3	153.7	627.8
1100	43.7	25.1	7.0	175.7	630.6
1200	51.7	40.1	10.3	413.0	716.7
1300	58.2	41.8	10.9	455.6	797.2
1400	55.6	41.0	10.3	422.3	583.3
1500	52.6	36.3	9.9	359.4	277.8
1600	48.3	32.1	8.7	279.3	133.3
1700	44.4	28.1	7.0	196.7	82.7

According to Table 3, by incorporating the reflectors and air cooling, it was observed that the average surface temperature of the panel had decreased slightly compared to that of Configuration 2. The variation of the power output in Configuration 3 as shown in Figure 5, is fairly similar to that of Configuration 2.

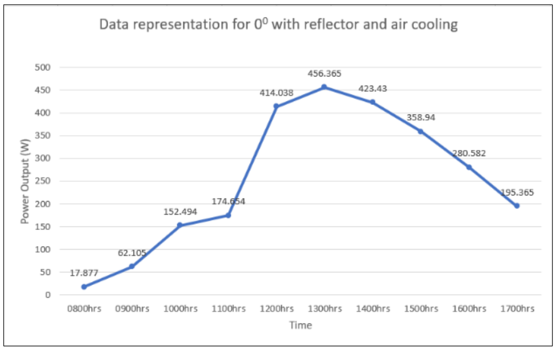

Figure 5. Power output vs. time in Configuration 3

Configuration 4: With reflectors and by incorporating both air and water cooling

According to Table 4, with air and water cooling in place, it was observed that the average panel surface temperature has reduced substantially. The variation of power output during the day is shown in Figure 6.

Table 4: Key operating parameters for the PV with reflector, air and water cooling (Configuration 4)

Time (hour of the day)	Average Surface Temperature (^{0}C)	Voltage (V)	Current (A)	Power Output (W)	Irradiance (W/m^2)
0800hrs	24.2	17.7	1.0	17.7	258.3
0900hrs	30.9	18.3	3.4	62.2	497.2
1000hrs	36.3	24.4	6.3	153.7	627.8
1100hrs	39.2	25.2	7.0	176.4	630.6
1200hrs	47.4	40.2	10.3	414.1	716.7
1300hrs	52.3	41.9	11.0	460.9	797.2
1400hrs	50.5	41.1	10.3	423.3	583.3
1500hrs	47.7	36.4	9.9	360.4	277.8
1600hrs	43.7	32.2	8.8	283.4	133.3
1700hrs	39.0	28.1	7.0	196.7	82.7

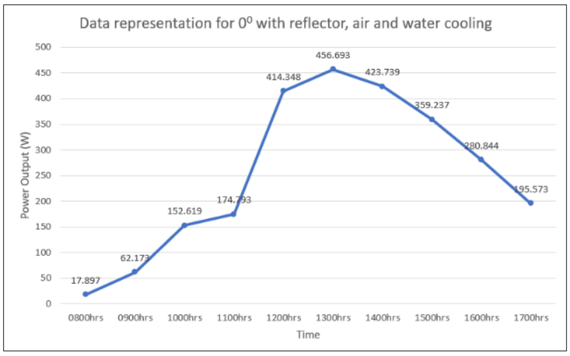

Figure 6. Power output vs. time in Configuration 4

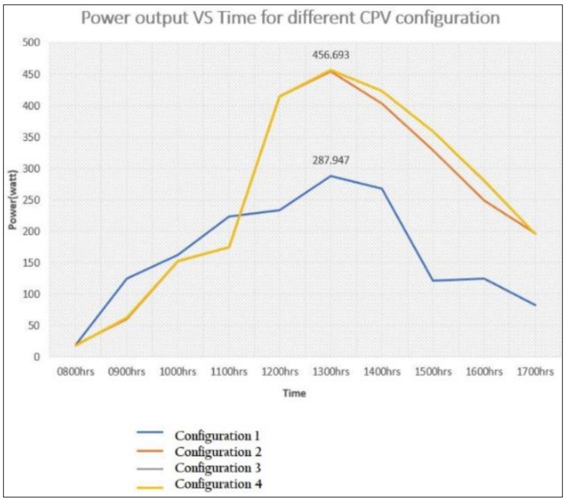

Figure 7. Comparison of power output of all configurations

Figure 7 provides a comparison of power output among all PV panel configurations.

IV. CONCLUSION

As far as the power output is concerned, it is evident that from 0800 hrs. to 1200 hrs., configuration 1 generates a higher power output than other configurations. However, after 1200 hrs. a higher power output is recorded by the other three configurations. By comparing configuration 2 with configuration 3, it is evident that a higher power output can be obtained when the panel cools down due to air cooling. The power output generated by configuration 4 does not show a significant difference to that of configuration 3. However, configuration 4 shows better temperature control due to air and water cooling that mitigates the degradation of the solar panel so that a longer lifetime can be expected for the equipment. The study shows that the conventional PV panel (Configuration 1) can be effectively used until 1200 hrs. and then by switching over to Configuration 4, it is possible to generate a higher power output while mitigating panel degradation due to better control of its surface temperature.

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