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# THE EFFECT OF AMBIENT TEMPERATURE AND SOLAR PANEL'S SURFACE TEMPERATURE ON OUTPUT PERFORMANCE OF SOLAR POWER SYSTEM.

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## ABSTRACT

*The effect of ambient temperature and solar panel's surface temperature on the output performance of a solar power system was studied. The solar panels rated 45Watts and 70Watts were placed separately in October and November on top of manual trackers located at (N04° 5´, E06° 54´), on the Eastern location of Ofrima complex in Abuja campus of the University of Port Harcourt, Rivers State, Nigeria. For 45W solar panel, the maximum average power output of 17.24Watts was obtained when the temperature difference between the solar panel's surface temperature and ambient temperature measured with digital thermometer was -0.67°C. Also, minimum average power output of 5.73Watts was obtained when the temperature difference between the solar panel's surface temperature and ambient temperature was 1.44°C. A similar trend of results was obtained from 70W rated solar panel. The absorbance layer employed in the production of the solar panel is assumed to be responsible for the high temperatures retained on the solar panel's surface when compared with the ambient temperatures. The results show that the lower the temperature difference between solar panel's surface temperature and ambient temperature, the higher the open circuit voltage and consequently the higher the power output and vice versa. It is therefore concluded from this study that the ambient and solar panel's surface temperatures have significant influence on the output power produced by solar power system.*

***Key words**: Temperature, Output Power, Solar Panel, Solar Tracker, Digital Thermometer.*

## INTRODUCTION

Renewable energy sources are self-renew sources that naturally and constantly replenish themselves and are regarded as virtually inexhaustible and less polluting, thus being environmentally friendly. Renewable energy sources are existing flows of energy from natural processes such as sun-shine, wind, flowing water (hydro-power) biological processes and geo-thermal heat flows. They may be used directly or used to create other more convenient forms of energy. Solar energy is thus one of the viable forms of renewable energy. Others include biomass, geothermal, wind, hydro, tidal.

Solar energy is simply the energy derived from the sun. It is the energy that comes from within the sun, which is a big ball of gas made up mostly of hydrogen and helium. It can also be seen as the energy produced when the sun's radiation impacts on a surface. In comparison to other renewable energy sources such as hydro power, wind and geothermal, solar has unmatched portability and flexibility. The sunlight that powers solar cells travels through space at 186,282 miles per hour to reach the earth 8.4minutes after leaving the surface of the sun (Benerjee, 2010).

Although, the solar energy that reaches the earth's surface is reduced due to water vapour, ozone layer absorption and scattering by air molecules, yet there is still plenty of power to collect out of the billions of megawatt per second generated by the sun. The energy obtained is either stored or used for some specific purposes. Some practical areas of solar energy usage include solar heater, solar cooker, solar Architecture, Photovoltaic technology, solar dryer, solar distiller.

The photoelectric effect is the phenomenon that explains the ejection of electrons from the surface of a metal when electromagnetic radiation falls on them. For each metal there is a well defined frequency called threshold frequency which must be exceeded for electron emission to occur, no matter how strong the intensity of light (Okeke, et al, 1987).

Photovoltaic cell is a device that converts sunlight to electricity (Muneer et al, 2005). A photovoltaic (PV) cell, also known as solar cell, is a semiconductor device that generates electricity when exposed to light. When light strikes a PV cell, the photons dislodge the electrons from the atoms of the cell. The free electrons then move through the cell, creating and filling holes in the cell. This movement of electrons and holes generates electricity. The physical process by which a PV cell converts light into electricity is known as the photovoltaic effect.

The photovoltaic effect is the electrical potential developed between two dissimilar materials when their common junction is illuminated with radiation of photons. The photovoltaic cell, thus, converts light directly into electricity (Patel, 1999).

The major types of materials for building PV cells include crystalline and thin films, which differ in terms of light absorption efficiency, energy conversion efficiency, manufacturing technology and cost of production (Oliva, 1998).

Table 1 compares PV materials in terms of their absorption efficiency, conversion efficiency and cost (Chou et al, 2004).

Converting solar energy to electricity through photovoltaic cells is one of the most exciting and practical scientific discoveries of the last hundred years. The use of solar power is far less damaging to the environment than burning fossil fuels to generate power. Solar power is thus a clean, pollution free, abundant power sources.

Using a PV system can be more expensive than buying power lines to a site currently without service (off-grid homes, more than 0.25 mile or 0.4 kilometer away from mountain-top communication system). How much PV need depends on the power loads, when wanting to completely replace the electrical purchases from utility with a PV system (Chow et al, 2007).

For solar energy, PV is identified to be of good potential for wide scale application. Port-Harcourt metropolis belongs to the subtropical climate region with typically hot and wet climate of characteristic distribution of total, diffuse and direct solar radiation (Akpabio et al, 2003).

The average solar radiation potential for a tropical climate region is about 16.4 ± 1.2 W / $m^2$ per day (Green, 2002). The average temperature distribution throughout the year in hot/wet climate region is about 28 ± 1 $^0$C (Olusegun, 1980).

Effect of the temperature on the output power can be quantitatively evaluated by

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examining the effects on current and voltage separately.

Patel, (1999) expressed the output power from solar panel as:

$$I_{sc} = I_0(1+\alpha.\Delta T) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ 1$$

$$V_{oc} = V_0(1-\beta.\Delta T) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ 2$$

Where :

$I_0$ is the short-circuit current at reference temperatute, T.

$V_0$ is the open-circuit voltage at reference temperature, T

$\alpha$ is the temperature coefficient of short-circuit current at reference temperature, T in per $^0$C.

$\beta$ is the temperature coefficient of open-circuit voltage at reference temperature, T in per $^0$C.

$$P_{out} = I_{sc} x V_{oc} = I_0(1+\alpha.\Delta T) x V_0(1-\beta.\Delta T) \quad \ldots\ldots\ 3$$

By ignoring a small term, $\alpha\beta(\Delta T)^2$ , Equation 3 becomes :

$$P_{out} = P_o[1+(\alpha-\beta).\Delta T] \quad \ldots\ldots\ldots\ldots\ldots\ 4$$

When the space program began to become important in the 1980's, the silicon-based solar cell was developed and consequently the solar panel collector was developed.

In other to use solar panel efficiently, it is necessary to have a solar collector which is a device that allows sunlight inside, absorbs the sunlight and changes it to heat and then traps the heat inside. The efficiency of a solar collector depends on time of the day, season of the year, the latitude of the area, weather conditions and temperature of the collector.

Inverters are employed in solar energy conversion. Inverter transforms the direct current electricity produced by the solar cells into the alternating current electricity commonly used in most homes for powering lights, appliances and gadgets. Inverters are used either as stand-alone inverters, grid-inverters or battery backup inverters. The inverters are usually connected to the charge controller, a device that regulate the input current from and flow of current to the battery banks.

It is therefore the purpose of this paper to investigate the effect of the ambient temperature and solar panel's surface temperature on the output performance of the solar power system.

## MATERIALS AND METHODS

In this work, the materials employed for taking the measurements were 45Watts Multi-silicon Solar Panel with model STP045-12/Rb, 70Watts Multi-silicon Solar panel with model STP070-12/Rb, 0.5KVA Prostar Inverter, 100Ah Prostar Battery, manually fabricated pole trackers, Digital Thermometer and Digital Multimeter.

Each Solar panel made of silicon cells was mounted on a manual tracker system in October – November, 2008 and October-December, 2009. The trackers were positioned at eastern location of Ofrima complex in Abuja Campus of University of Port Harcourt, Rivers State, Nigeria. The trackers were mounted temporarily facing a particular direction with the aid of pivoted joint anchored by screws and nuts. This gives opportunity of rotating the panel to the desired angle and height.

The temperature of the solar panel's surface and the ambient temperature were recorded using a digital thermometer at intervals of 15 minutes daily from 7a.m till 6.15p.m when output current dropped to zero.

A digital multimeter was employed to measure the open circuit voltage and the short circuit current from the terminals of the solar panel. The corresponding values of a.c voltage, a.c current were measured from the inverter output to determine the effective a.c power output at each instance. The weather was characterized by varied heavy rain, light rain, humid air, dry air, high sunlight intensity, low sunlight intensity, and cloudiness during the periods of measurements in both years.

The relation below then determined the output power generated by the solar panels at different weather conditions:

$$P_{out} = I_{sc} \text{ x } V_{oc} \quad \ldots\ldots\ldots\ldots\ldots\ldots.. \quad 3$$

where :

$I_{sc}$ = Short circuit current in Amperes.

$V_{oc}$ = Open Circuit voltage in Volts.

$P_{out}$ = Output Power in Watts.

Regardless of size of a typical silicon photovoltaic cell, its efficiency depends on the intensity of sunlight striking the surface of the cell at a specified angle of inclination, the percentage of light converted to electrical energy which corresponds to irradiance (flux of energy per area) and spectrum of the sun light incident falling on the tilt surface.

The efficiency of the component of solar power generation is correlated, that is the efficiency of the solar panel determines the efficiency in the output of the inverter. Equation 5 is the equation for the efficiency of the inverter.

$$\text{Efficiency} = \frac{\text{a.c output voltage}}{\text{d.c input voltage}} \text{ x } 100 \ldots\ldots 5$$

Hence, the equation for the efficiency of the solar panel is:

$$E = \frac{P_m}{\varepsilon \bullet A_s} \text{ x } 100\% \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 6$$

Where: $\dot{E}$ = Efficiency of the energy conversion

$P_m$ = Maximum Power Point

$\varepsilon$ = Light Input irradiance (W/m$^2$)

$A_s$ = Surface Area (m$^2$)

Figure 1 shows typical structural parts of a solar panel (http://www.visualdictionaryonline.com/energy/solar-energy.php) placed in a frame.

Figure 2 illustrates the experimental set-up.

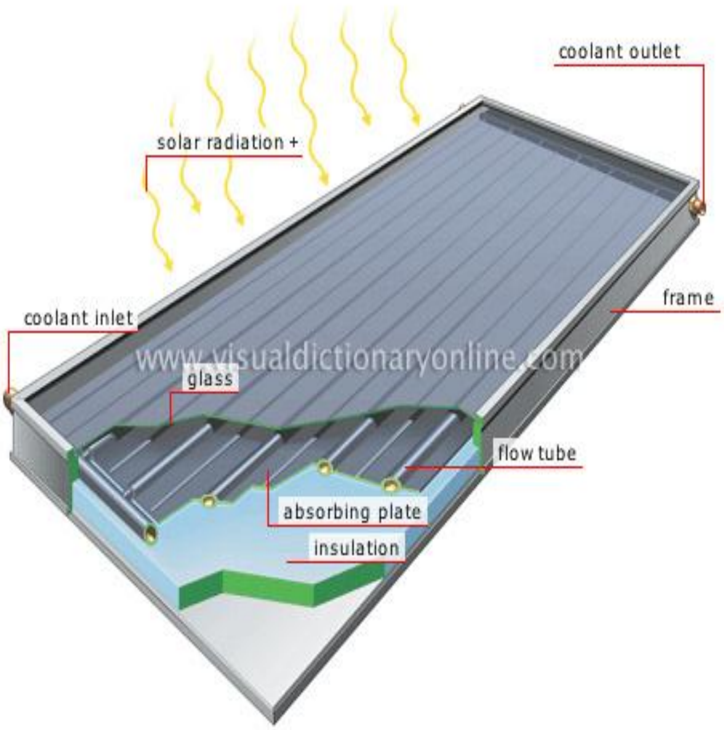


**Fig. 1:** A typical structure of a solar panel.

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**REPRESENTATION OF THE SETUP**

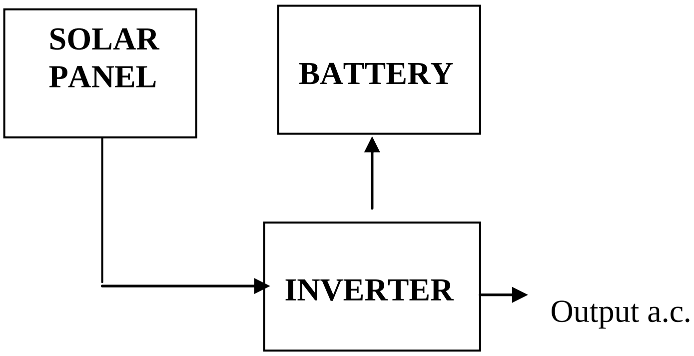


Fig. 2: Block diagram of the experimental setup**.**

**Table 1:** A comparison of PV materials

| | Crystalline | | | Thin film | | |
|---|---|---|---|---|---|---|
| Material | Single - Si | Poly - Si | GaAs | a-Si | CdTe | $CuInS_2$ |
| Absorption efficiency | low | low | medium | high | high | High |
| Conversion efficiency | 15 – 20 % | 10 –14% | 25 – 30% | 5 – 9% | 7% | 18% |
| Cost | low | low | high | medium | medium | high |

A typical data obtained for day 1 with recorded weather conditions is shown in table 2.

**Table 2:** Readings for Day 1

| **Time** | **V / V** | **I / A** | **P/ W** | **$T_{atm}$(°C)** | **$T_{pan}$(°C)** | **Remark** |
|---|---|---|---|---|---|---|
| 7.45am | 18.60 | 0.15 | 2.79 | 28 | 28 | Moderate Sunlight |
| 8.00am | 18.88 | 0.16 | 3.02 | 28 | 28 | Moderate Sunlight |
| 8.15am | 18.60 | 0.16 | 2.98 | 28 | 28 | Moderate Sunlight |
| 8.30am | 18.20 | 0.12 | 2.18 | 28 | 29 | Moderate Sunlight |
| 8.45am | 18.30 | 0.12 | 2.19 | 27 | 28 | Moderate Sunlight |
| 9.00am | 17.80 | 0.07 | 1.25 | 27 | 28 | Moderate Sunlight |
| 9.15am | 17.49 | 0.07 | 1.22 | 28 | 28 | Very Low Intensity |
| 9.30am | 16.25 | 0.04 | 0.65 | 31 | 28 | Moderate Sunlight |
| 9.45am | 16.39 | 0.04 | 0.66 | 32 | 29 | Moderate Sunlight |
| 10.00am | 18.13 | 0.10 | 1.00 | 34 | 30 | Low Intensity |
| 10.15am | 18.86 | 0.15 | 1.82 | 35 | 32 | Moderate Sunlight |
| 10.30am | 18.16 | 0.09 | 1.63 | 36 | 32 | High Intensity |
| 10.45am | 19.51 | 0.30 | 5.86 | 37 | 33 | Low Intensity |
| 11.00am | 18.49 | 0.13 | 2.40 | 36 | 32 | Low Intensity |
| 11.15am | 19.50 | 0.31 | 6.05 | 36 | 32 | Low Intensity |
| 11.30am | 19.86 | 0.59 | 11.71 | 35 | 31 | Low Intensity |
| 11.45am | 20.03 | 0.90 | 18.03 | 38 | 32 | High Intensity |
| 12.00pm | 20.54 | 0.94 | 19.31 | 36 | 32 | Moderate Sunlight |
| 12.15pm | 19.89 | 1.04 | 20.69 | 36 | 32 | High Intensity |
| 12.30pm | 19.81 | 0.40 | 7.92 | 36 | 32 | Moderate Sunlight |
| 12.45pm | 20.14 | 0.40 | 8.05 | 36 | 34 | Moderate Sunlight |
| 1.00pm | 19.89 | 1.14 | 22.67 | 35 | 34 | Moderate Sunlight |
| 1.15pm | 19.87 | 0.64 | 12.72 | 37 | 35 | Moderate Sunlight |
| 1.30pm | 20.14 | 0.83 | 18.79 | 35 | 39 | High Intensity |
| 1.45pm | 20.21 | 0.93 | 18.79 | 35 | 35 | Moderate Sunlight |
| 2.00pm | 20.00 | 0.70 | 14.00 | 34 | 34 | Moderate Sunlight |
| 2.15pm | 20.00 | 0.70 | 14.00 | 32 | 31 | Moderate Sunlight |
| 2.30pm | 25.00 | 0.85 | 21.25 | 32 | 31 | High Intensity |
| 2.45pm | 19.55 | 0.61 | 11.93 | 34 | 33 | Moderate Sunlight |
| 3.00pm | 9.97 | 0.50 | 4.99 | 32 | 36 | Moderate Sunlight |
| 3.15pm | 10.50 | 0.60 | 6.30 | 31 | 35 | High Intensity |
| 3.30pm | 11.02 | 0.42 | 4.63 | 31 | 33 | High Intensity |
| 3.45pm | 19.48 | 0.36 | 7.01 | 32 | 34 | Low Intensity |
| 4.00pm | 19.41 | 0.38 | 7.37 | 27 | 33 | Moderate Sunlight |
| 4.15pm | 19.43 | 0.67 | 13.02 | 32 | 34 | Low Intensity |
| 4.30pm | 19.31 | 0.75 | 14.48 | 29 | 30 | Low Intensity |
| 4.45pm | 19.43 | 0.15 | 2.91 | 29 | 30 | Moderate Sunlight |
| 5.00pm | 19.06 | 0.10 | 1.96 | 30 | 30 | Moderate Sunlight |
| 5.15pm | 18.67 | 0.30 | 5.60 | 30 | 30 | Moderate Sunlight |
| 5.30pm | 18.07 | 0.20 | 3.61 | 30 | 29 | Very Low Intensity |
| 5.45pm | 18.23 | 0.40 | 7.29 | 28 | 29 | Cloudy |
| 6.00pm | 11.06 | 0.03 | 0.33 | 28 | 30 | Cloudy |
| 6.15pm | 6.80 | 0.00 | 0.00 | 29 | 27 | Cloudy |

The averages of Power, $P_{ave}$., Ambient temperature, $T_{ave(amb)}$ and solar panel's surface temperature, $T_{ave(panel)}$ obtained for each day is shown in table 3 below .

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**Table 3**: A Table Showing Average Daily Power, Ambient Temperature and Solar Panel's Surface Temperature.

| **Days** | $\mathbf{P}_{ave.}$ (watts) | $\mathbf{T}_{ave.(amb)}$ (°C) | $\mathbf{T}_{ave.(panel)}$(°C) |
|---|---|---|---|
| Day 1 | 7.79 | 32.09 | 31.40 |
| Day2 | 14.40 | 32.76 | 31.20 |
| Day3 | 17.24 | 31.89 | 31.22 |
| Day4 | 9.21 | 28.93 | 29.76 |
| Day5 | 11.02 | 26.70 | 28.35 |
| Day6 | 11.10 | 27.09 | 28.46 |
| Day7 | 11.27 | 26.96 | 28.70 |
| Day8 | 13.49 | 28.35 | 29.91 |
| Day9 | 9.69 | 26.09 | 27.57 |
| Day10 | 9.69 | 28.71 | 29.91 |
| Day11 | 9.55 | 29.09 | 30.53 |
| Day12 | 9.72 | 29.17 | 30.50 |
| Day13 | 8.57 | 29.06 | 30.36 |
| Day14 | 7.40 | 30.89 | 33.47 |
| Day15 | 6.08 | 30.80 | 33.45 |
| Day16 | 6.92 | 32.02 | 33.46 |
| Day17 | 6.05 | 30.86 | 33.49 |
| Day18 | 5.73 | 32.02 | 33.46 |

## RESULT AND DISCUSSION

During the study, the maximum power point was obtained by taking the product of open circuit voltage ($V_{oc}$) and short circuit current ($I_{sc}$) from the data collected for each day from 7.00am to 6.15pm and at most 6.30pm depending on when the short circuit current gives 0.00A at an interval of 15minutes. The graph of voltage and current against time of the day shows the same trend for all the days of data collection (Fig. 3). Currents and Voltages increase during the bright sunny period and gradually decreases as the sun set. In fact, at 6.30p.m, zero current was recorded.

The typical non-linear *i-v* characteristics obtained for day 7 is shown in figure 4. The graphs show similar trends for all other days of measurement. The voltage and current increases gradually at some instant, sharply at another instance and decreases considerably at other instance. This confirms the inconsistency in the quantity of solar radiation that impinges the surface of the solar panel for energy conversion. This inconsistency could be attributed to the solar intensity and other weather conditions such as cloudiness, ozone layer e.t.c. Hence, the values of open circuit voltage and the short circuit current produced by the solar panel for each day depend on the weather conditions at that moment of data collection.

Ambient temperature and the temperature of the solar panel's surface were also taken, in cognizance of the weather conditions. The analysis based on experimental data shows that ambient temperature influences the temperature on the surface of solar panel.

With 45W solar panel, the maximum power output of 22.67Watts was obtained at 1.00pm when the ambient temperature and solar panel's surface temperature were $35^0$C and $34^0$C respectively on day 1 during a clear and sunny weather. This maximum power output was achieved when the temperature difference between solar panel's surface temperature and ambient temperatures ($T_{panel} - T_{ambient}$) was -$1^0$C. A minimum power output of 0.33Watts was obtained at 6.00p.m when the ambient temperature and solar panel's surface temperature were $28^0$C and $30^0$C respectively. This indicates a temperature difference of +$2^0$C (Table 2).

On day 3, the temperatures on the surface of solar panel and ambient temperature at 11.30am were $32^0$C and $36^0$C respectively with maximum power output of 47.16Watts. Thus, maximum power output of 47.16Watts was obtained at temperature difference of -$4^0$C. The minimum power output of 0.27 Watts was obtained at 6.00p.m when the temperature difference was $1^0$C ($T_{panel}$ = $28^0$C and $T_{ambient}$ = $27^0$C). At a point, the output power becomes absolutely zero when the sunlight disappeared and its intensity was no longer felt (figs. 5 and 6).

On day 14, the maximum power was 15.91Watts at 11.15am. The power output fell to 0Watts at 6.15pm. The maximum power output obtained on day 15 was 11.85Watts. This is achieved at 12.30p.m. It was observed that the same trend holds for 70 Watts rated Solar Panel.

Generally, the weather conditions were varied and unstable which affected the power generation and temperature of the solar panel during operating period. Consequently, there were fluctuations of the electrical output power.

The average power produced for each day at average ambient temperature and solar panel's surface temperature is shown in table 3. The maximum average power output of 17.24 Watts was obtained on day 3 when the ambient temperature and solar panel's surface temperature were $31.89^0$C and $31.22^0$C respectively. The minimum average power output of 5.73 Watts was obtained when the ambient and solar panel's surface temperature were $32.02^0$C and $33.46^0$C respectively (Fig. 7).

Thus, maximum 17.24 Watts was obtained at temperature difference of -$0.67^0$C and the minimum average power output of 5.73 Watts was obtained at temperature difference of $1.44^0$C (fig. 8).

It is therefore observed from the trend line (fig. 8) that power output increases with decreasing temperature difference between solar panel's surface temperature and ambient temperature. This clearly shows that the ambient temperature and solar panel's surface temperature have significant effect on the power generated by the solar power system.

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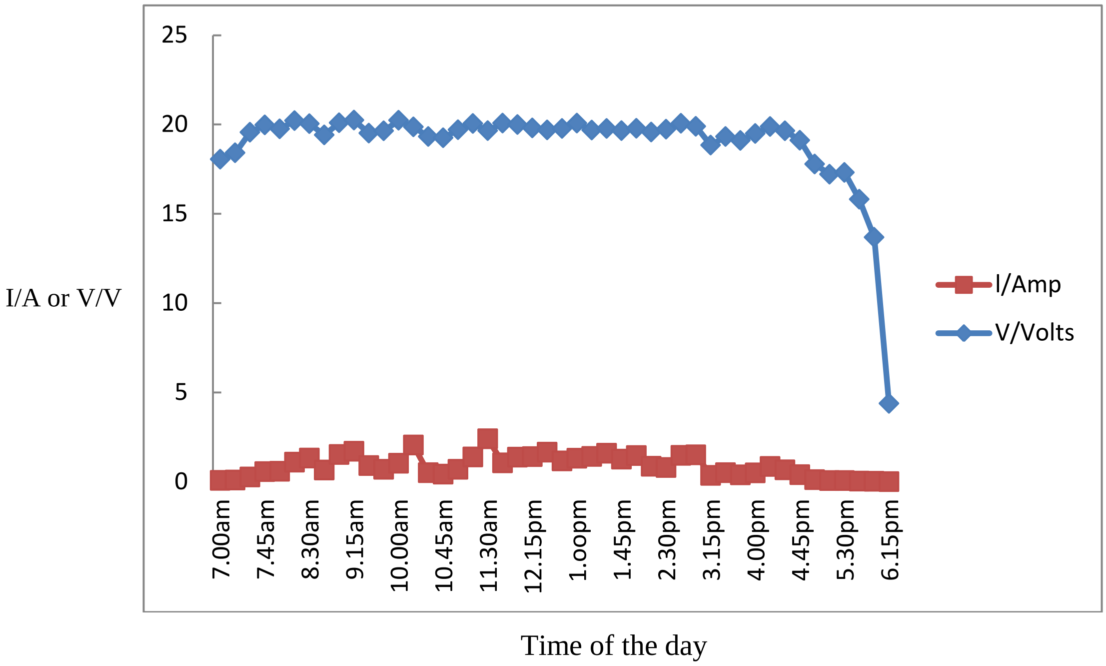


**Fig. 3:** A Graph of Current and Voltage against Time of day 3.

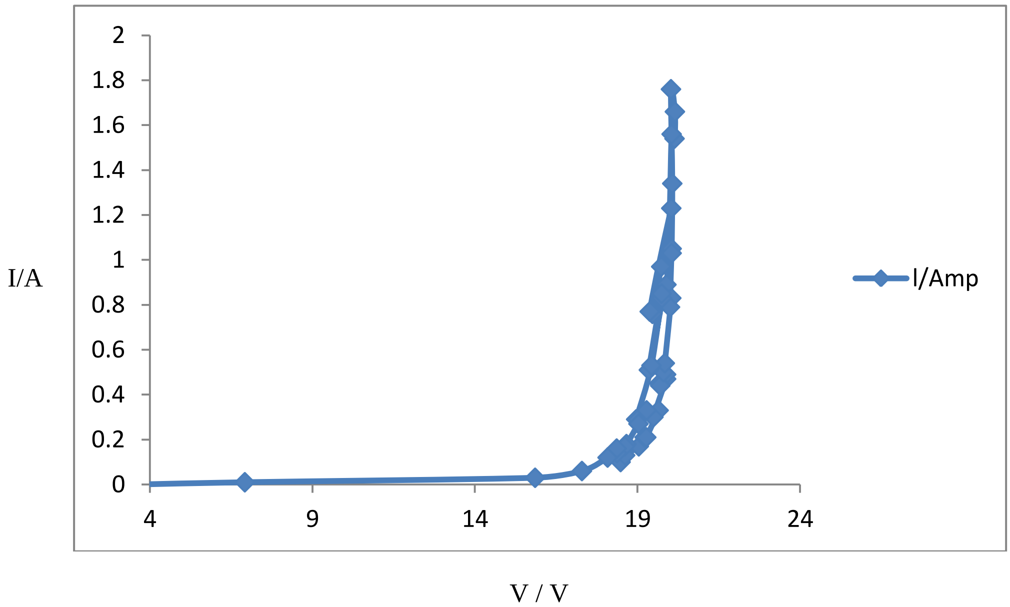


**Fig.4:** The *i-v* characteristic curve of solar panel performance for day 7

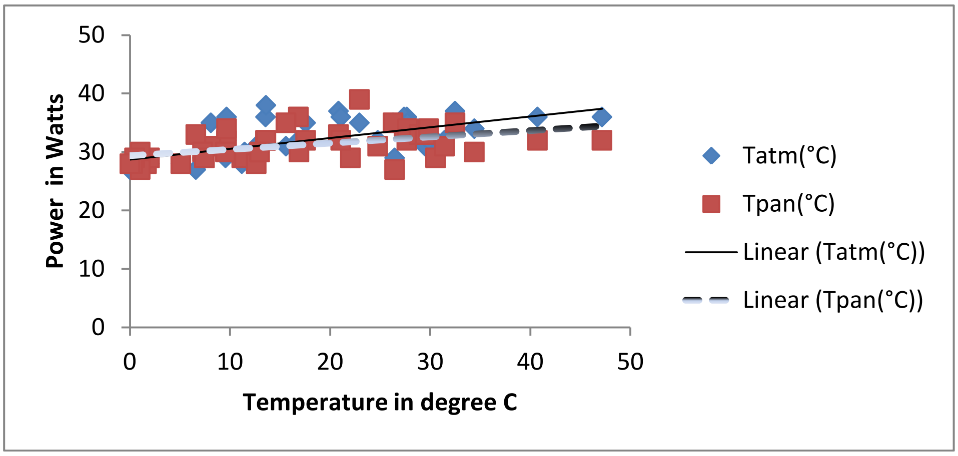


**Fig.5:** A graph of power output against ambient and solar panel's surface temperature for day 3.

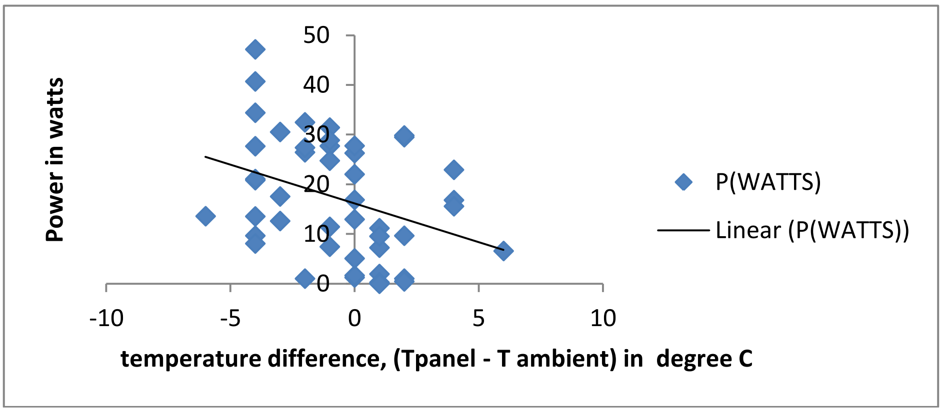


**Fig.6:** A graph of power output against temperature difference ($T_{panel} - T_{ambient}$) for day 3.

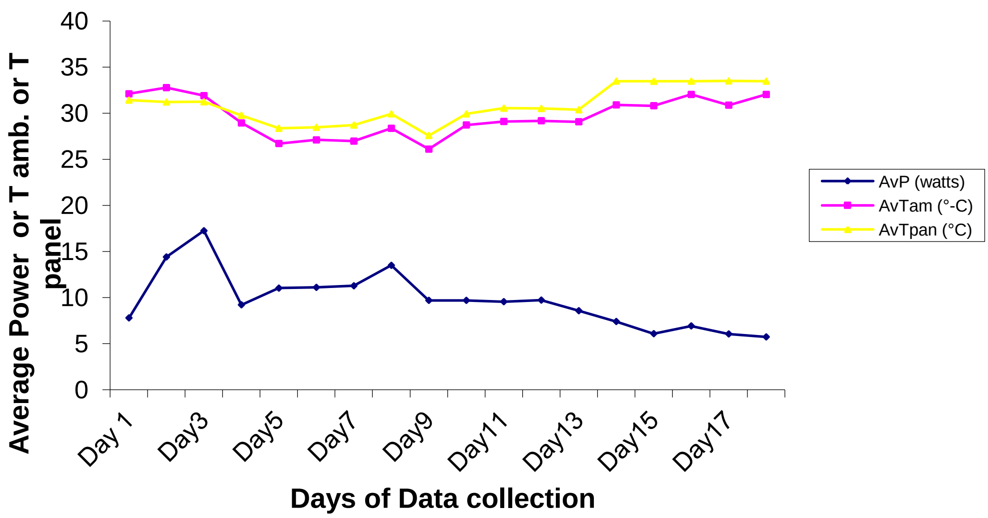


**Fig. 7**: Graph of Average Power, Average Ambient temperature and Solar Panel's surface temperature for each day of data collection.

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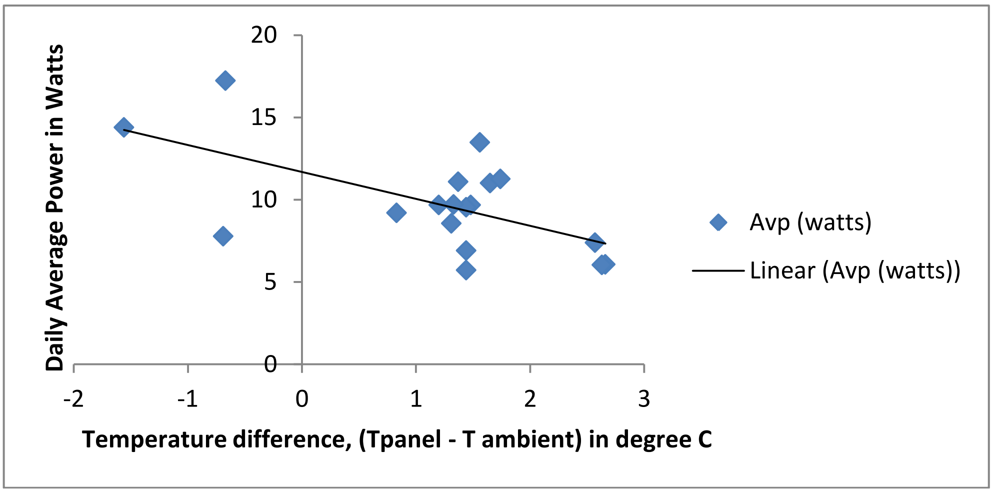


**Fig. 8:** The trendline showing Daily Average Power against temperature difference.

## CONCLUSION

The effect of solar panel's surface temperature and ambient temperature on the performance of solar power system was studied. It is noted that as the temperature difference between solar panel's surface and ambient temperature increases, the power output decreases. Hence, temperatures (solar panel's surface temperature and ambient temperature) are considered to have significant effect on the output power delivered by the solar power system.

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