CHARACTERIZATION OF THE PERFORMANCE OF PHOTOVOLTAIC (PV) MODULES USING SOLAR METER

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ABSTRACT

In this work a commercial Solar Photovoltaics (PV) was characterized using the I–V characteristics in Chukwuemeka Odumegwu Ojukwu University (COOU), Uli campus. An investigation of the performance and device parameters of a mono crystalline silicon cell at different conditions of solar irradiance was studied with a Solar Meter using standard characteristic curves to obtain output parameters. The characterization of the PV was possible by monitoring PV panel's performance at different times of the day and at different weather conditions. The outdoor exposure tests were carried on in March. For each day of this field experiment, measurements of irradiance H and the corresponding values of current I, voltage V and temperature θ were made. The corresponding values of I, V, θ at 8.00 am, 8.30 am, 9.00 am, etc. were added and averaged. The data collected were used for the analysis of the H, I, V, θ and power P. The output parameters obtained are Short Circuit Current I_{sc} = 4.2 Amps, Open Circuit Voltage V_{oc} = 23.55 volts, Optimum Current I_{mp} = 3.80 Amps, Optimum Voltage V_{op} = 23.70 Volts, Optimum Output Power P_{mpp} = 98.43 watts, Fill Factor ff = 84.0 %, and Conversion Efficiency η = 16 %. From the averaged weather conditions for the set of readings, our results indicate that the month of March is bright with enough solar radiation. The intensity of solar energy was highly not invariant. It increased from zero at sun rise to its peak at 12.30 pm. This peak was 635 W/m^2, about 47 %, less than the solar constant (1353 Wm^{-2}). This figure is dependable because our η = 16 % is comparable to that supplied by the manufacturer, measured at standard test condition. By implications COOU, Uli, is a sustainable environment for solar energy conversion and utilization.

Keywords: *Silicon Modules/Panel, I–V Characteristics, Output Parameters, Solar Meter*

INTRODUCTION

The development of new and sustainable source of energy today is one of the greatest challenges facing the world. Between 1950 and 1987 global energy consumption increased by 300 % and assuming no major changes in use, it is expected to increase by almost 50 % in the next twenty years (Campbell, 1991). Fossil fuels predominate – oil (38 %), coal (28 %) and natural gas (22 %) – with nuclear fission and hydroelectric power each contributing 6 % (Campbell, 1991). This energy mix cannot persist for a long time if man's continued existence on earth is to be assured. If the present rate of civilization is to be maintained while the world's growing population is sustained we must seek an alternative source of energy supply that is free from global warming.

Of all the available energy sources to man's development, solar or radiant energy are the most promising and the oldest. It can be harnessed and used in various applications. The earth receives more energy from the sun than is consumed by mankind in a year (Ugwuoke, 2000). Thus the solar energy that the earth receives can meet man's energy needs. The years since the mid-1970s have seen the birth of a new physics-based industry (Hill, 1991) which involves harnessing solar energy for human development.

Solar energy or solar power is simply the energy radiated from the sun. It is a potentially limitless and environmentally friendly energy source. It is promising because of its simplicity in harnessing and the abundance of the sun's energy everywhere on the earth. Solar radiation is involved either directly or indirectly with almost every process taking place in the earth-atmosphere system.

When solar energy impinges the surface of the earth, some areas get more solar radiation per year. The radiation of the sun reaching the earth, distributed over a range of wavelengths from 300 nm to 4 μm approximately, is partly reflected by the atmosphere and partly transmitted to the earth's surface. The radiation outside the atmosphere is distributed along the different wavelengths in a similar fashion to the radiation of a 'black body' following Planck's law, whereas at the surface of the earth the atmosphere selectively absorbs the radiation at certain wavelengths.
It is estimated that every square centimeter of the sun radiate energy into space at a rate of 3.8×10^{26} W per day. Of the total energy radiated, the earth intercepts only a very small fraction, $\frac{1}{5.8\times10^{-19}}$ or 1.7×10^{18} J every sec (Williams, 1975; Okeke, 2006).
The most important parameter in the survey of solar radiation measurement is the energy received outside the earth's surface or in outer space. This parameter, *a mean rate of solar energy that arrive at the top of the atmosphere*, which has a degree of constancy 1353 Wm^{-2} (Dixon and Leslie, 1978), when compared to that of energy received on the ground is the rate at which energy is received on a unit surface or per unit of collector area, normal or perpendicular to the sun's direction, in free space at the earth's mean distance from the sun.
Rotation of the earth about its axis brings about changes in energy received from the sun. On a clear sunshine day, the energy the earth recieves increases from zero at sunrise to a max at solar noon and decreases to zero at sunset. At any moment however, the clouds may intercept the sun and decrease the energy to a value due to the diffuse radiation (Dixon and Leslie, 1978).
The effects of the earth's atmosphere and the Fraunhofer absorption lines modify the solar radiation reaching the surface of the earth. Solar energy is reduced by various atmospheric conditions which are not the same all over the world. The quantity of energy received at various points on the globe varies. Solar insolation is required in order to harness solar power or solar radiant energy.

This work characterizes a commercial solar PV using the I–V characteristics in Chukwuemeka Odumegwu Ojukwu University, Uli campus, which is situated at latitude $6° 10'$ N of the equator and longitude 6◦ 45′ E in the Northern hemisphere within the standard sea-level atmosphere with variation in sunlight, temperature, sun angle and reflections at surfaces.

MATERIALS AND METHOD

The following materials were used in the experimental study in order to determine the solar PV characteristics.

- A photovoltaic mono crystalline solar panel (AT-5020 20W).
- A multi meter (milli ammeter, and voltmeter).
- Insulated wires with alligator clips / other cables.
- SM 206 solar meter.
- A thermometer.
- A stop clock.

The PV module or panel used in this work was monitored using SM 206 solar meter.

Fig. 1 Mono Crystalline Silicon Solar Panel with specifications AT-5020, 20W

Figure 1 shows the pictorial representation of the PV module used for this work. The outdoor exposure tests carried out in this work was done in March, from 8.00 am – 5.30 pm each day. I–V characteristics of the PV panel at certain conditions, e.g. weather, were measured. The experimental set up for the work is shown in Figure *2*.

Fig. 2 Operational Set up of Instruments

For each day of this field experiment, measurements of irradiance H and the corresponding values of current I, voltage V and temperature θ were made. The corresponding values of I, V, θ at 8.00 am, 8.30 am, 9.00 am, etc. were added and averaged. The data collected were used for the analysis of the H, I, V, θ and power P.

RESULTS AND DISCUSSION

By adding together the corresponding values of I, the corresponding values of V, and the corresponding values of temperature θ within the stipulated times of 8.00 am, 8.30 am, 9.00 am and so on, at 30 minutes intervals up to 5.30 pm in fifteen days of March and dividing accordingly by the number of occurrence within the time intervals, the mean values were obtained. These average values of readings at particular times of the fifteen different days in March were used for the analysis of the solar radiation flux or solar irradiance, current I, voltage V, power P and temperature θ within daily time intervals of 30 minutes.

Also plots of current against V, power against voltage, power against current, solar irradiance against power, temperature against power, solar irradiance against daily time, temperature against daily time, as well as solar irradiance verses current, solar irradiance verses voltage, temperature verses current, and temperature verses voltage were also plotted.

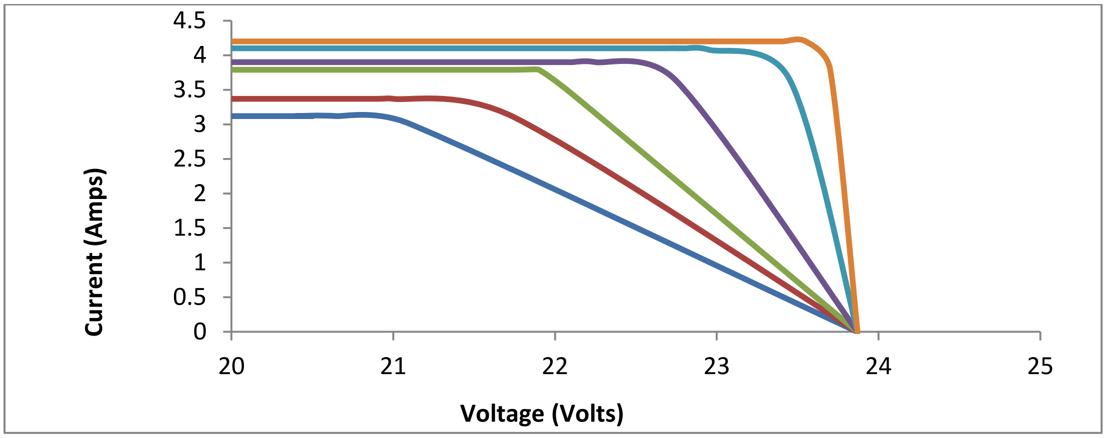

Fig. 3: Plot of Current I against Voltage V of the PV Module in Sunlight (From 8.00 am - 5.30 am) for the Months of March

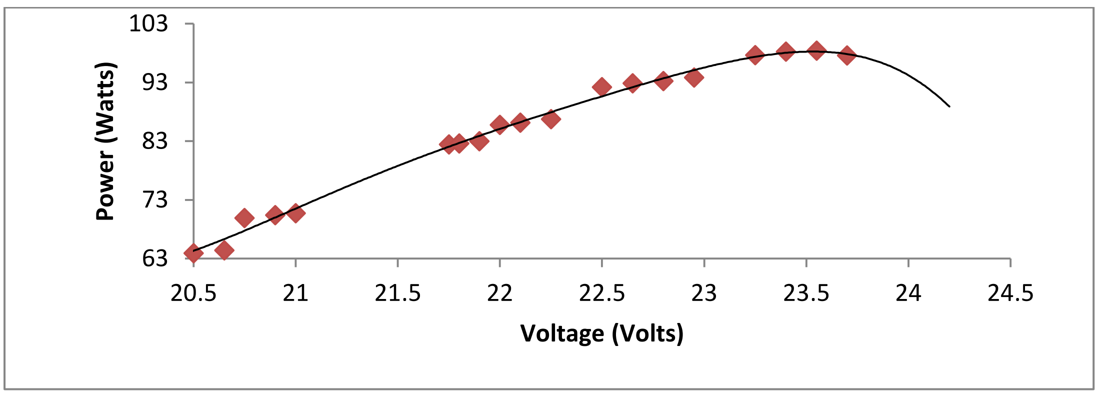

Fig. 4: Plot of Power P against Voltage V of the PV Module in Sunlight (From 8 am - 5.30 am) for the Month of March

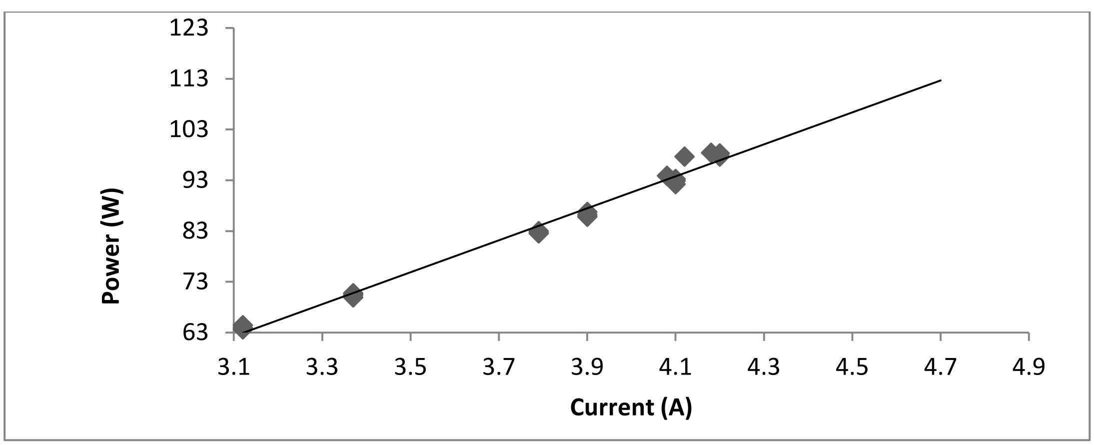

Fig. 5: Plot of Power (P) against Current (I) of the PV Module in Sunlight (From8.00 am - 5.30 pm) for the Month of March

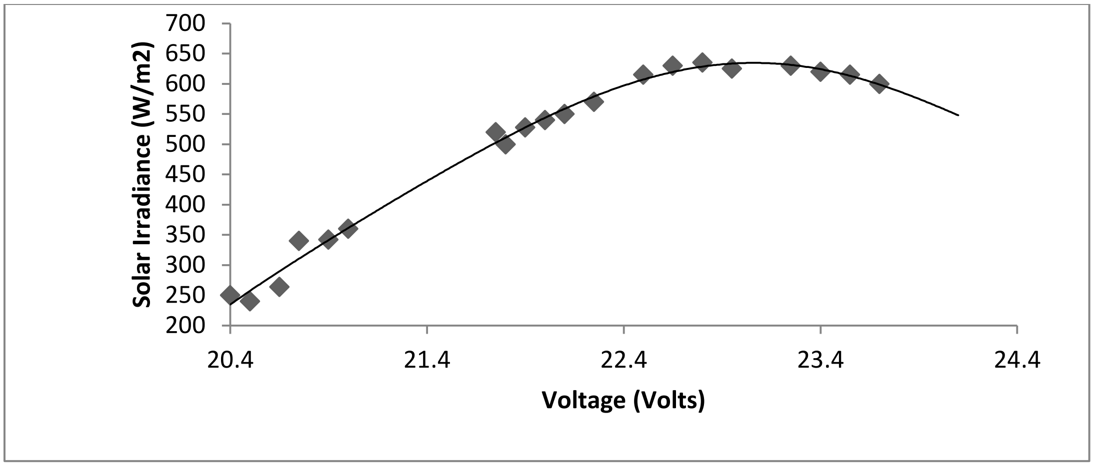

Fig. 6: Graph of Solar Irradiance (H) vs. Voltage (V) Characteristics of PV Module in Sunlight (From 8.00 am - 5.30 pm) for the Month of March

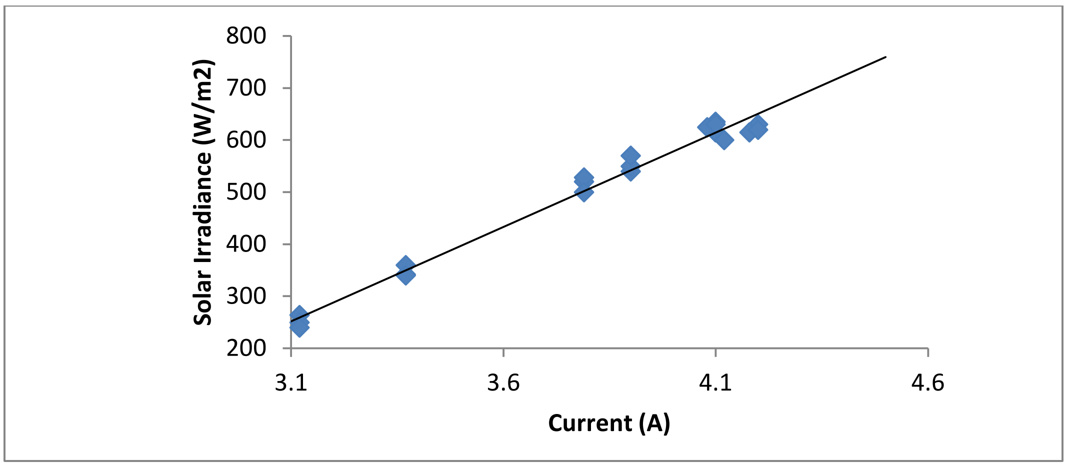

Fig. 7: Graph of Solar Irradiance against Current of the PV Module in Sunlight (From 8.00 am - 5.30 pm) for the Month of March

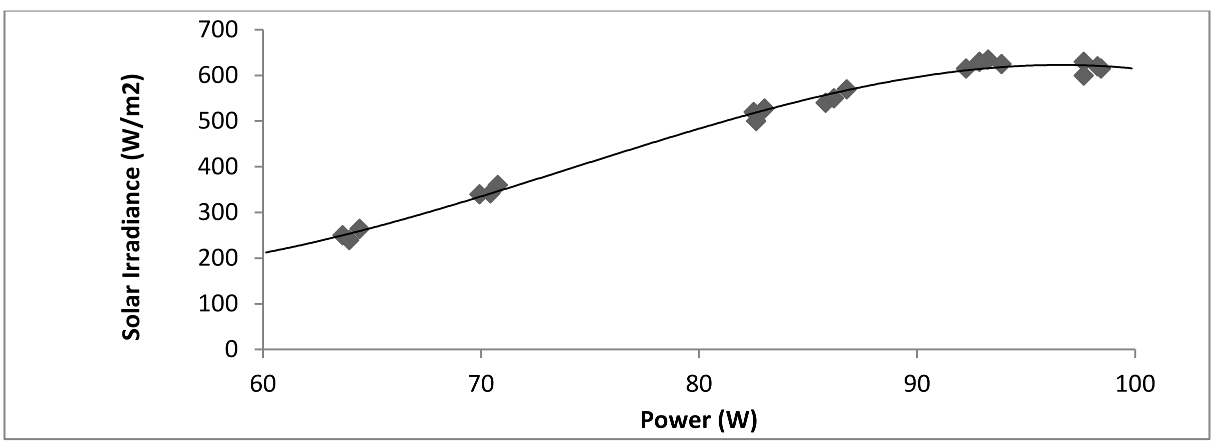

Fig. 8: Graph of Solar Irradiance (H) against Power (P) of the PV Module in Sunlight (8.00 am - 5.30 pm) for the Month of March

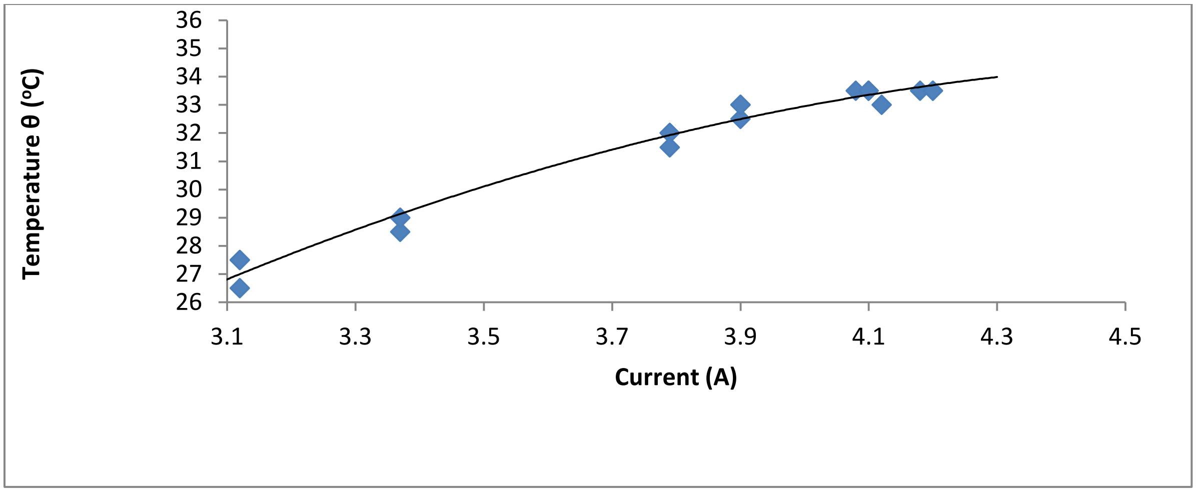

Fig. 9: Graph of Temp **(θ)** vs. Current (I) of the PV Module in Sunlight (From 8.00 am - 5.30 pm) for the Month of March

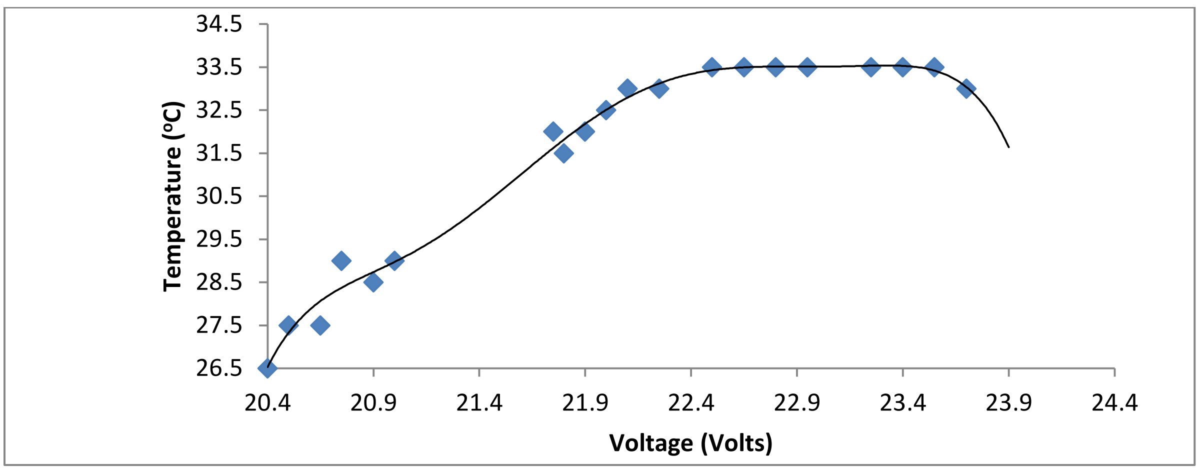

Fig. 10: Graph of Temp (θ) vs. Voltage (V) of the PV Module in Sunlight (From 8.00 am - 5.30 pm) for the Month of March

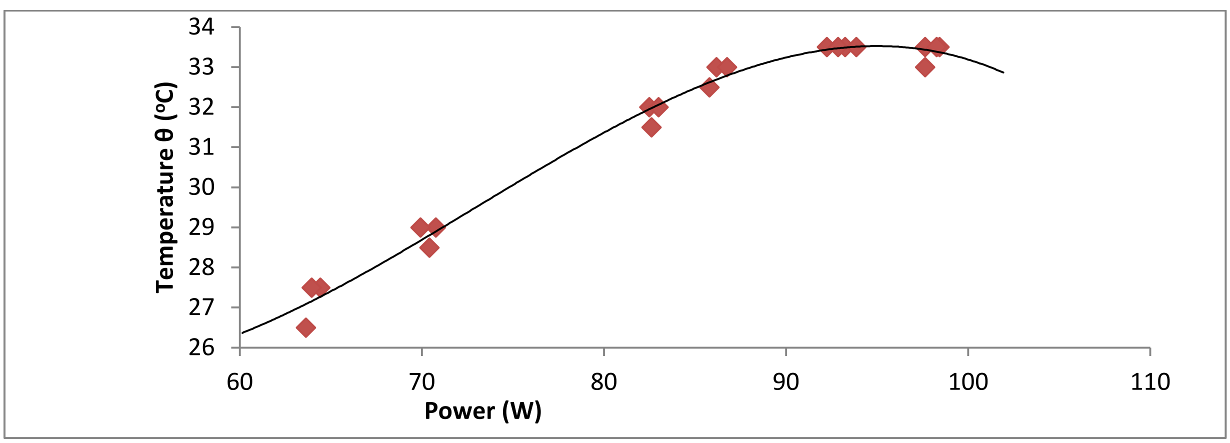

Fig. 11: Plot of Temp (θ) against Power (P) of the PV Module in Sunlight (8.00 am - 5.30 pm) for the

Month of March

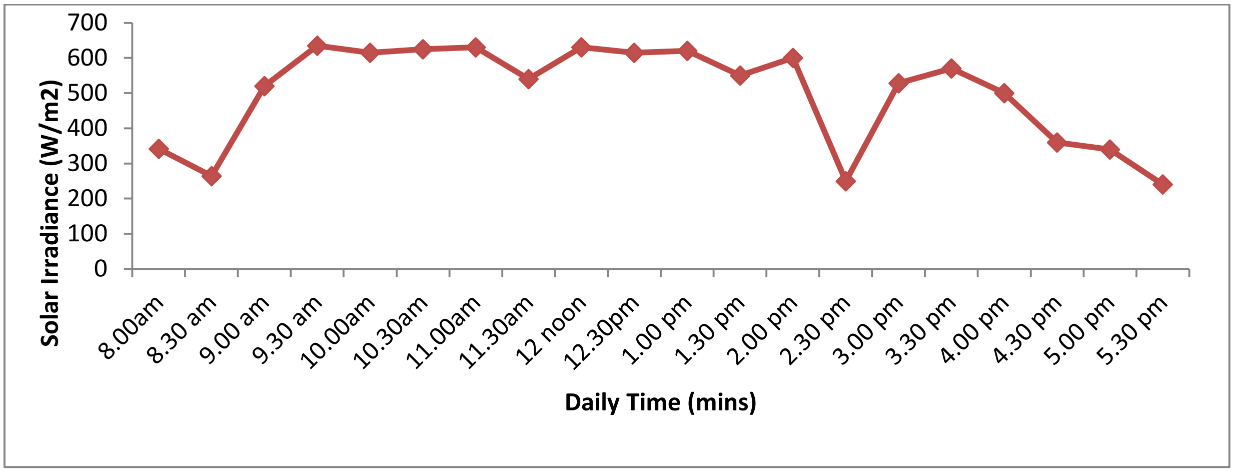

Fig. 12: Plot of Solar Irradiance (H) vs. Daily Time (T) of the PV Module in Sunlight (8.00 am -5.30 pm) for the Month of March

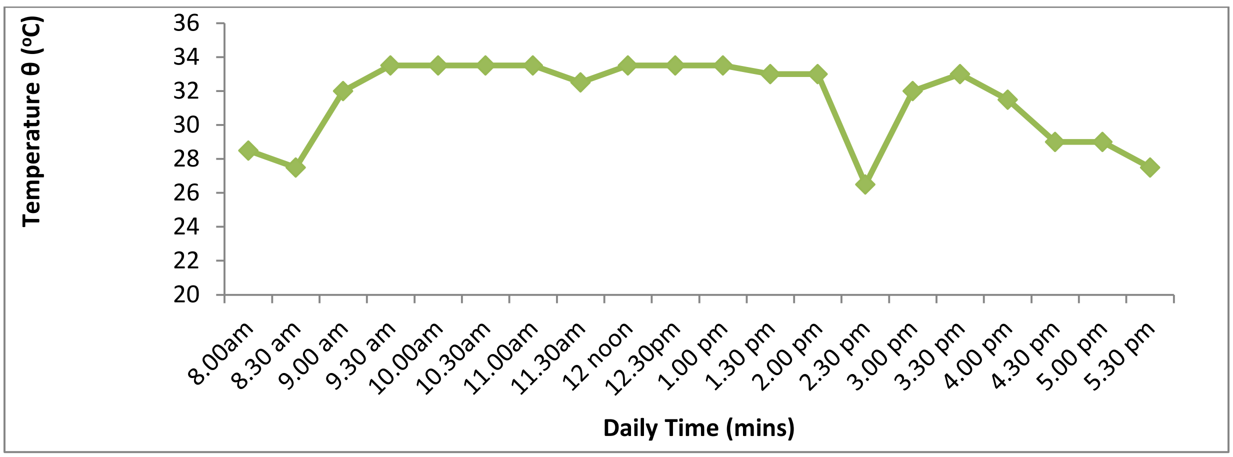

Fig. 13: Plot of Temperature (θ) against Daily Time (T) of the PV Module in Sunlight (8.00 am - 5.30 pm) for the Month of March

I–V characteristics of mono crystalline silicon (Si) solar cell studied is shown in Figure 3 while that of power against voltage and power against current is shown in figure 4 and 5. Both the I-V and P-V curves are in line with that of other researchers such as Mukund (1999) and Masters (2004). The output parameters are in line with that of Wenham *et al. (2007) and Ibrahim (2011a)* under Standard Test Conditions.

In Figure 3, I–V characteristics of our 20 watts panel for the month of March was illuminated with solar irradiance H of 630, 635, 570, 528, 360 and 264 W/m^2 and six current – voltage curves and the constant current source, were generated.

The module delivered a maximum output current of 4.2 Amps with voltage of 23.55 volts and temperature of 33.5 ^{o}C under full sun, and power output was 97.650 watts. On a cloudy day, it would be lower than that of dull morning or dusk time, overcast weather, dull, dew, etc. such as 264 W/m^2. The conditions shadowed the intensities.

The top left of I–V curve at zero voltage is the short circuit current, I_{sc} = 4.2 Amps. The bottom right of the curve at zero current is the open circuit voltage, V_{oc} = 24.0 volts. The curves have knee points in between the left and right hand sides.

In the left region of the knee points, the cell worked like a constant current source, generating voltage to match with the load resistance. In the right region, the current dropped rapidly with small rise in voltage, the cell worked like a constant voltage source with an internal resistance. The photocurrent was a maximum under full bright sun (1.0 sun). On a partially sunny day, the photocurrent diminished in direct proportion to sun intensity. I–V characteristics of PV module shifted down at lower sun intensity, with small reduction in voltage. On a cloudy day, therefore the short circuit current decreased significantly. The reduction in the open circuit voltage, however, was small. The maximum power point of current I_{mpp} = 3.80 A, and of voltage V_{mpp} = 23.70 V. These are in agreement with www.greenrhinoenergy.com (2013).

Figure 4 is the P–V characteristics of the PV module in sunlight. It was the plot of the output power of the panel against the voltage. The power terminated downward at 63.96. In the PV power circuits the modules operate close to the knee point for maximum power. Optimum Output Power P_{mpp} = 98.43 W.

The Maximum Power point (MPP) is found on the current / voltage characteristic curve at the point where the gradient is 1 - hence, the angle of the gradient is 45 °. At the MPP, the power is at its maximum. The gradient of the power / voltage characteristic curve equals 0 and the angle of gradient is also 0 °. From the graph, the filling factor can be determined as the relationship of area B to area A.

From Figure 4, the plot of Power verses Voltage is similar to Figure 6, the plot of Solar Irradiance against Voltage, Solar Irradiance reached the maximum range of 600 W/m^2 to 635 W/m^2 where the graphs depict non-linearity in line with The German Energy Society (2008).

The linear graphs of Power verses Current, Figure 5, show that the power is directly proportional to the current. The linear graphs of Figure 7, Solar Irradiance against Current, show that the short-circuit current was linearly dependent upon the irradiance (i.e. if the irradiance was doubled, the current also was doubled).

The photo conversion efficiency of the PV cell is given by,

$$\eta = \frac{electrical\ power\ output}{solar\ power\ impinging\ the\ cell} = P_{out}/P_{in}$$

The higher the efficiency, the higher the output power under a given illumination (Mukund, 1999). Under solar irradiance of 635 Wm^2 and 360 W/m^2:

$$(a)\ \eta = \frac{93.252}{635}\ x\ \frac{100}{1} = 16.69\%$$

$$(b)\ \eta = \frac{70.770}{360}\ x\ \frac{100}{1} = 19.66\%$$

The photo conversion efficiency of the cell is insensitive to the solar radiation in the practically working range. The efficiency is practically the same in (a) and (b), which means the same conversion efficiency is gotten on a bright sunny day and on a cloudy. When irradiance drops by half, the electricity generated also reduces by half (The German Energy Society, 2008). Low power output was gotten on a cloudy day only because of the lower solar energy impinging the cell (Mukund, 1999). In Figure 8, at the least solar irradiance of 220 W/m^2, the corresponding power is 60.00 watts. The power rose to maximum value of 98.43 as the voltage increased to 23.55 V when the temp was 33.5 ^{o}C at 12.30 pm.

The power output of solar cells was reduced by high temperatures. The effect of temperature on the power shown in Figure 9 is quantitatively evaluated by examining the effects on the current and voltage separately (Figures 9 and 10). As Temperature increased, the short-circuit current of the cell increased, but the open-circuit voltage decreased. The increase in the current is much less than the decrease in the voltage, the net effect is the decrease in power at high operating temperatures such as from 33 ^{o} C when the power is 86.775 W. The cell produced less current but greater voltage with net gain in the power output at cold temperature due to activities in the band gap energy. The working temperature of the solar cell θ_c depends exclusively on the irradiance H and on the ambient temperature θ_a according to the relation:

$$\theta_c = \theta_a + C_1 H \quad (1)$$

where the value of C_1 is taken to be 0.03 ($^0C/Wm^2$) (Malik and Damit, 2003). Thus, as the Sun's brightness increased the output voltage and power decreased as temperature increased.
Figure 12 and Figure 13, which is a plot of solar irradiance versus time and temperature against time, the solar Irradiance has maximum value of $635\,W/m^2$ at 9.30 am and minimum value of $240\,W/m^2$ at 5.30 pm. The highest Temperature recorded was 33.5 ^{o} C from 9.30-11.00 am and 12.00 noon – 1.00 pm. The lowest temperature recorded was 26.5 ^{o} C at 2.30 pm. A rise in the solar radiation intensity is swapped over by an increase in temperature. The performance of a solar cell is related with its angle of tilt with the horizontal. The tilt angle influences the amount of energy collected by a PV module. The max conversion efficiency of the cell obtained in this work is,

$$\eta = \frac{98.439}{615}\ x\ 100 = 16.0\% \text{ at } 33.5^0C.$$

16.0 % was recorded as the maximum conversion efficiency, cell temperature was calculated as

$$\theta_c = \theta_a + (0.03)615$$
$$= 33.5 + 18.45$$
$$\approx 52.O^0C$$

The recorded efficiency of the cell was less than the efficiency measured at STC. The solar cell efficiency varies as irradiance varies but at a rate different from the variation of irradiance. Our solar cell efficiency lies in the range of 15.2 % – 16.1% compared to that of Ibrahim 10.08 % – 12.54 %. Both sets of efficiencies are comparable to those supplied by the manufacturer, measured at STC: 14 % – 17 % as in literature.

CONCLUSION

Current–Voltage (I–V) characteristic of solar PV was determined with the aid of Solar Meter. I–V characteristic of PV module shifted down at lower sun intensity in the morning, dull or evening times. The cell produced less current and higher voltage at lower temperature, e.g. in March, at 365 Wm^{-2}, I = 4.10 A, V = 22.80 V and θ = 33.5 ^{o} C; but at 340 Wm^{-2}, I = 3.37 A, V = 20.75 V and θ = 29.0 ^{o} C. The voltage drop was very small. This is in agreement with the researchers; Lorenzo (1994), Joshi (1994), Rummel (1995), Mukund (1999) Elminir (2006), Tiwari and Dubey 2010 and Ibrahim (2011c).
Temperature has a non-negligible effect on the solar cell I–V characteristics. With increasing temperature, the photocurrent (short circuit current) of the cell increased slightly where as the open circuit voltage decreased linearly, owing to the exponential increase in saturation current. The cell produced less current but greater voltage, with net gain in the power output at cold temperature. The slight increase in the photocurrent arose from a decrease in the band gap energy of the material as the temperature increased.
The cell produced no power at zero voltage or zero current. Rather, it produced the maximum power at voltage corresponding to the knee point of the I–V curve. The PV power circuits are therefore designed in such a way that the modules operate close to the knee point for maximum power.

The output parameters obtained are Short Circuit Current I_{sc} = 4.2 Amps, Open Circuit Voltage V_{oc} = 23.55 volts, Optimum Current I_{mp} = 3.80 Amps, Optimum Voltage V_{op} = 23.70 Volts, Optimum Output Power P_{mpp} = 98.43 watts, Fill Factor ff = 84.0 %, and Conversion Efficiency η = 16 %.

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