THE EFFECTS OF SOLAR IRRADIANCE AND AMBIENT TEMPERATURE ON SOLAR PV MODULE OUTPUT IN NORTHERN GHANA

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ABSTRACT

Solar energy is abundant. It is however low grade energy and cannot be easily used in the form it occurs for work. Converting solar energy directly to electricity, using solar photovoltaic (PV) modules is however a low efficiency process. Optimizing this conversion, especially in the face of the high cost of solar panels, is thus desirable. Towards this end, it is necessary to know the maximum output periods of solar modules and the conditions for maximum panel output. This paper is the result of a study of the effects of solar irradiance and ambient temperature on the output of solar PV modules. In this study, using polycrystalline and amorphous silicon PV panels - the most widely used in the Northern, Upper East and Upper West regions, the output current and voltage from the solar panels (PV modules), and hence the output power, were measured at hourly intervals of time. The corresponding temperature at each reading was also recorded. This was carried out in the dry season and in the rainy season. From analysis of the results, it was found that the times of high charging current, and that is the best time to put out the solar panels for charging is between 9:00 am to 11:00 am on sunny days. On cloudy days, charging should be extended to the evening. With regards to irradiance and temperature, it was found that for both types of panels, the output depended a lot on irradiance. Ambient temperatures above 30°C cause a slight (5 - 9%) decrease in output. Thus, the study shows that high irradiance, coupled with temperatures between 26°C - 30 °C are necessary for high panel output.

KEY DESCRIPTORS: Solar, Photovoltaic, module, irradiance, ambient temperature

INTRODUCTION

Solar energy is abundant. Converting solar energy directly to electricity using photovoltaic (PV) modules however, is only about 12 - 14 % efficient (Derrick, 1989). Considering this low conversion efficiency and the high cost of solar PV

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modules, (Loreineau, 1994), it is desirable to maximize the output of solar PV modules to make solar PV power production more cost effective. This is especially so as solar electricity is environmentally friendly, a renewable energy resource and easily the best source of electricity in remote off-grid areas. As electricity is an engine of social and industrial development, the socio-economic and industrial development of such off- grid areas (mostly rural), depend a lot on not only the provision of solar electricity, but also on how efficiently the solar energy conversion systems operate. This efficiency, in the main, depends on the output of the solar panels. Thus factors affecting the output of solar PV panels need to be studied, in order to make the best of solar PV systems. One of such factors is ambient temperature. It has been observed that solar PV module output tends to decline at high ambient temperatures (Radziemska, 2003). The other is solar irradiance. Thus, in the interest of development in general, and rural development in particular, through the efficient use of solar electricity, from solar PV modules, it has been of interest to know:

i. how solar module output varied with changes (in this case, increase) in ambient temperature.
ii. the best time to put solar modules out in the sun, in order to charge storage batteries. This happens to be necessary in the case of Solar Home Systems (SHS) solar lamps and other solar devices whose modules are not mounted in fixed positions, but have to be put out daily in the sun to charge the batteries connected to their output terminals.
iii. how the output of the solar modules changed on sunny, cloudy and rainy days, i.e. for various levels of solar irradiance.

To study and find answers to some or all of the issues raised, the polycrystalline and amorphous silicon solar modules were considered , for the simple reason that they are practically the only ones used in solar systems and devices in the Northern, Upper East and Upper West regions. A total of about 3000Wp were installed from 2001 to 2006 (BEST Solar, 2006). Even though the study was carried out in the Northern region, the results are applicable to the three northern regions, since they have averagely the same level of incident solar radiation (Akuffo, 1998).

Besides the introduction, the rest of the paper discusses the materials used in the study, the method of using the materials to obtain the data and a discussion of the results. The conclusion and recommendations then follow on the basis of the results and discussion.

MATERIALS

i. For the measurements, the following set of apparatus was used: Polycrystalline silicon (Si) panel with the following characteristics; 65Wp, (12 to 21)V, rated charging current 4A and short-circuit current 4.7A, maximum system open circuit voltage of 600V series and PV module rating of $1000 W/m^2$ at 25^0C cell temperature.

These panels form the basis of PV modules used in charging 140Ah, 12V batteries in Solar Home Systems (SHS) and in solar PV systems supplying electric power to schools, clinics and communication systems.

ii. 7 Wp thin film amorphous silicon panels with rated voltage: 12V nominal (7V minimum, 30V maximum). This type of panel forms the basis of solar PV modules for charging 3Ah, 12V batteries used in solar lamps; .

iii. AVD830B multimeters (200mV – 500V AC/DC and 10A DC)

iv. Meteorological thermometer (0^0C – 120^0C).

v. A Casio watch, set to beep hourly.

METHOD

The solar panels were set up in such a way as to receive maximum irradiance from the sun; i.e. in the North – South direction, inclined at an angle of 45^0 to the south. The angle is determined approximately by adding 15^0 to the location latitude. The 65Wp and 7Wp panels were connected to charge 140Ah, 12V and 3Ah, 12V batteries respectively. One multi-meter, set to measure the d.c. output voltage, was connected across panel terminals before the battery connection. The other, set to measure the output current, was connected in series with, but before the positive terminal of the battery. Daily hourly readings of voltage, current and temperature were taken, beginning at 7:00 am to 5:00pm. The readings were taken for a period of six months: December –February in the dry season, and June to August in the rainy season. Hourly readings on clear sunny days and on cloudy days including rainy days were averaged for each corresponding hour.

RESULTS AND DISCUSSION

From the experimental data obtained, their subsequent tabular and graphical representation, the following observations were made with regards to the times of high current output, the effects of ambient temperature variations and irradiance on panel output. Current output, instead of panel power output, is considered for the simple reason that with regards to solar PV panel output, of interest is the battery charging current, converted from incident solar energy, by the panel. This consideration stems from the fact that the solar energy, more often than not, is first of all accumulated in the battery as electric charge, for a more steady supply of electrical energy from the battery to the load.

Output of 65Wp Polycrystalline Silicon Solar panel (module) on Sunny Days

The output values of the 65Wp solar panel were averaged over the number of sunny days and presented in Table 1.

Table 1: **Averaged readings for the 65Wp polycrystalline silicon module on sunny days**

Voltage/V	current/A	Power/W	Temperature/^{0}C	Time/hr
17.3	1.45	25.1	25.6	7:00am
18.4	1.95	35.9	25.8	8:00am
18.6	3.49	64.9	26	9:00am
18.5	3.54	65.5	27.4	10:00am
18.3	3.52	64.4	30.1	11:00am
18.1	3.48	63.0	33.2	12:00pm
18.1	3.42	62.0	35.4	1:00pm
18.0	3.4	61.2	36.8	2:00pm
17.9	3.35	60.5	35.9	3:00pm
17.9	3.35	60.0	34.0	4:00pm
17.8	3.32	59.1	30.8	5:00pm

Source: Field Survey (2006)

High Current Output Times and Effect of High Ambient Temperatures

From Table 1, the high current output time is between 9:00 am to 11:00 am, the average current output being 3.5A for temperatures between 26°C – 30°C. The maximum output occurs at 27.4°C.

Effect of Ambient Temperature

For ambient temperatures above 30°C, the current output of the polycrystalline silicon panel (module) drops from a maximum of 3.54 A at 27.4°C to 3.4 A at 36.8°C. Thus ambient temperatures above 30°C lower the current output by 4%. From 2: 00 pm to 5:00 pm, the ambient temperature falls from 36.8°C to 30.8°C; and one would have expected an increase in current output. On the contrary, the current output falls with the drop in temperature, following the falling level of incident solar radiation as the evening takes hold. This signifies that the current output depends a lot on solar irradiance.

Output of the 65Wp Polycrystalline Silicon Panel(module) on Cloudy days:

In Table 2 below are averaged output values of the 65Wp panel on sunny days. From 9:00 am to 11:00 am, as captured in Table 2,the output current is 2.4A on the average, at an average temperature of 26°C.

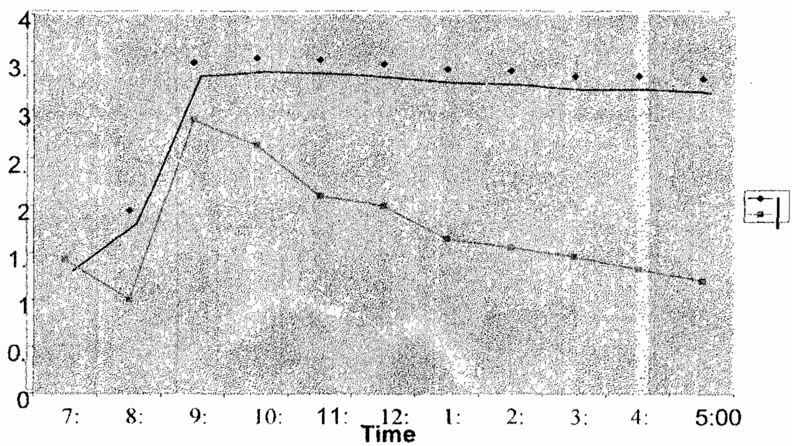
Table 2: **Averaged readings for the 65Wp polycrystalline silicon module on cloudy days**

Voltage/V	Current/A	Power/W	Time/hr.	Temperature/0C
16.6	1.43	23.7	7:00am	24.6
16.8	1.61	27.1	8:00am	25.4
17.4	2.39	41.6	9:00am	26.4
17.9	2.63	47.1	10:00am	25.8
16.6	2.10	34.9	11:00am	25.2
16.4	2.00	32.8	12:00pm	24.2
16.2	1.64	26.6	1:00pm	24.7
16.2	1.55	25.1	2:00pm	25.4
16.0	1.46	23.4	3:00pm	25.5
15.8	1.32	20.9	4:00pm	25.6
15.8	1.20	19.0	5:00pm	24.0

Source: Field survey (2006)

Comparing the average current output on cloudy days, (2.40A), to the output on sunny days, (3.49A), at a similar temperature of 26°C, it is seen that the panel output between 9:00 am to 11:00 am drops by 34% on cloudy days. Furthermore, on cloudy days, from 12:00 pm to 5:00 pm, with the mean temperature hardly getting above 26°C, the average current output, towards the evenings, falls from 2.40A to 1.20A. This represents a drastic drop of 66% from the output on sunny days. This goes to confirm the earlier observation that the current output of the panel (or module) depends on the amount of solar irradiance. These observations are shown in graphical form in Fig.1

Fig.1 Graph of Current Output of 65Wp Solar PV panel on



Output of the 7Wp Amorphous Silicon panel (module) on sunny days:

In Table 3 are the averaged output values of the 7Wp amorphous silicon panel on sunny days.

Table 3: **Averaged readings for the 7Wp amorphous silicon module on sunny days**

Voltage/V	Current/A	Power/W	Temperature/0C	Time/hr
17.5	0.24	4.2	25.6	7:00am
18.0	0.25	4.5	25.8	8:00am
18.9	0.32	6.6	26.0	9:00am
19.2	0.35	6.7	27.4	10:00am
19.2	0.35	6.7	30.1	11:00am
19.1	0.33	6.3	33.2	12:00pm
18.95	0.33	6.3	35.4	1:00pm
18.9	0.32	6.0	36.8	2:00pm
18.88	0.32	6.0	35.9	3:00pm
18.85	0.31	6.0	34.0	4:00pm
18.80	0.31	5.8	30.8	5:00pm

Source: Field survey (2006)

From Table 3, it is seen that from 9:00 am to 11:00 am, the average current output is 0.34A for temperatures between 26 – 30oC. For temperatures above 30oC, the current output drops from 0.35A to 0.32A, at a temperature of 36.8oC. That is the current output of the amorphous silicon panel decreases by 9% for temperatures above 30oC.

Output of the 7Wp Amorphous Silicon panel on Cloudy Days

Table 4 below shows the averaged output values of the 7Wp silicon panelon cloudy days.

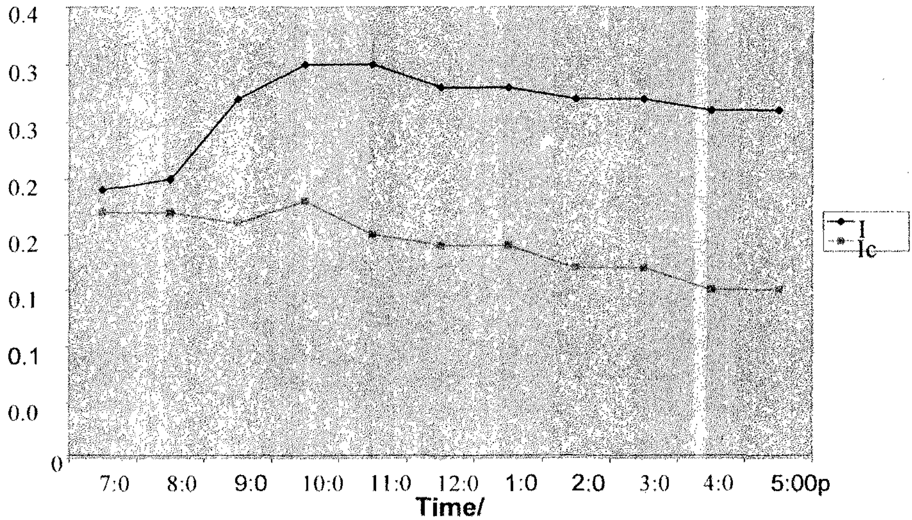
Table 4:. **Averaged readings for the 7Wp silicon panel on cloudy days.**

Voltage/V	Current/A	Power/W	Temperature/0C	Time/hr
16.3	0.22	3.6	24.6	7:00am
16.2	0.22	3.6	25.4	8:00am
16.4	0.21	3.4	26.4	9:00am
16.4	0.23	3.8	25.8	10:00am
16.0	0.20	3.2	25.2	11:00am
14.6	0.19	2.8	24.2	12:00pm
14.5	0.19	2.8	24.7	1:00pm
14.3	0.17	2.4	25.4	2:00pm
14.3	0.17	2.4	25.5	3:00pm
14.1	0.15	2.1	25.6	4:00pm
14.0	0.15	2.1	24.0	5:00pm

Source: Field survey (2006)

For cloudy days (Table 4), the current output is averagely 0.20A at an average temperature of 26oC. Comparing this output to the output of the panel on sunny days (0.32A) at the same temperature , it can be seen that the amorphous silicon solar panel (module) output decreases by 28%on cloudy days, even though the ambient temperature may be considered to be in the optimal range. This strongly suggests the dependence of the solar panel output on solar irradiance. The variation in current output of the amorphous silicon panel on sunny and cloudy days is shown on the graph in fig. 2 .

Fig.2 Graph of cur- rent output of amorphous sili-



CONCLUSION AND RECOMMENDATIONS

Conclusion

From the analysis of the data obtained, it may be concluded that:

i. On sunny days, i.e. days of high irradiance , the best charging times, i.e. the times of high current output, are between 9:00 – 11: 00 am, at temperatures between 26oC to 30oC.

ii. For ambient temperatures above 30oC, the polycrystalline silicon panel output drops by 4%, whereas the amorphous silicon panel output decreases by 9%, showing that high ambient temperatures do have a lowering effect on panel output.

iii. For both types of solar panels (modules), a clear , sunny sky, i.e. high solar irradiance, is vital for high panel output.

iv. On days of low irradiance or high diffuse radiation (cloudy days), the output of the polycrystalline type of solar panel falls by over 50% that for sunny days, even at temperatures lower than 270C; and that of the amorphous silicon panel by 28%.

v. From (i) - (iv) it can be inferred that a high irradiance coupled with temperatures between 26oC - 300C are necessary for high solar panel output.

Recommendations:

Considering the conclusions drawn from analysis of the experimental data, namely, the times optimal conditions prevail for high current output, the following recommendations may be made:

- The maximum output times for solar panels of the amorphous and polycrystalline silicon types are between 9:00am – 11:00am on sunny days.

- On cloudy days, for solar lamps and also for solar home systems (SHS), where the panel is not mounted at a fixed position, the charging period should be extended from morning to evening. Also, if cloudy conditions persist continuously for 3 or more days, the lamp or battery will need some booster charging from the mains or other electric energy source.

- For off-grid areas (mostly the rural areas), diesel/petrol electric generators should also be supplied alongside solar PV systems, to be used at instances of continuous cloudy conditions, when the charging current from the solar modules is down by more than 50%. Some of the power from the generator will be used to booster-charge accumulator batteries connected to the solar PV panels, and the remaining to supply vital systems that must be operational at all times e.g. vaccine refrigerators, emergency units in rural clinics, emergency communication links, social centers used for community education and/or rural industry.

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