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DETERMINATION OF TEMPERATURE COEFFICIENTS OF OPEN-CIRCUIT VOLTAGE AND SHORT-CIRCUIT CURRENT OF MULTI-CRYSTALLINE SILICON SOLAR CELLS USING EMPIRICAL APPROACH.

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ABSTRACT

The temperature coefficients of short- circuit current (α) and open-circuit voltage (β) were determined from the measured data. 45 Watts and 70 Watts multi-crystalline Silicon Solar cells, 100Ah battery, 0.5kVA inverter and digital thermometer were employed for the data collection. These equipment were set up in the University of Port Harcourt environs (latitude 4^0 55' 58" North and longitude of 6^0 59' 55" East) during the period of October to December. The power output of multi-crystalline silicon solar cells decreases by every ^{0}C rise in temperature above the operating temperature. Typically, multi-crystalline silicon solar cells rated 45 Watts power output decreases by 63% while 70 Watts power output decreases by 48% for every ^{0}C rise in operating temperature.

INTRODUCTION

Solar energy is the energy derived from the Sun. It is a form of energy that is renewable. It naturally and continuously replenishes itself after usage compared with conventional form of energy.

Solar energy is the energy of electromagnetic radiation released as a result of the fusion of the hydrogen nuclei into Helium nuclei.

$$2H_1 + 2H_1 \rightarrow {}^4_2He + E$$
……………………1

In the process, energy E is released as electromagnetic radiation called SUN. That is why Sun is referred to as enormous nuclei reaction.

Other types of renewable energy, that is, non conventional energy are wind energy, bio-mass, tidal, hydro and geothermal energy.

Solar energy is advantageous because it is noiseless, clean source, pollution free and relatively no cost of maintenance since no mechanical moving parts are involved in its installation.

Solar cell is the unit that captures energy embedded in the solar radiation (photons) and converts it to electricity. The combinations of interconnected solar cells make up the solar module. Also, further combinations of solar modules are the solar panel.

Photovoltaic cell is a device that converts sunlight to electricity. 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 (Muneer et al, 2005).

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.

Direct radiation is an incident beam which is directly on the earth's surface. Another type of solar radiation is diffused radiation which scattered before reaching the surface of the earth.

The intensity of solar energy at noon on a clear day is about $1000 W/m^2$ with most in form of direct radiation (http://www1.eere.energy.gov/solar/photovoltaics_program.html).

The energy obtained from solar 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.

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 $16.4 \pm 1.2 W / m^2$ per day (Green, 2002).

The average temperature distribution throughout the year in hot/wet climate region is about $28 \pm 1\ ^0C$ (Olusegun, 1980).

Amusan, et al, (2012) studied the effect of Ambient Temperature and Solar Panel's Surface temperature on output performance of Solar power system. 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. Maximum average power of 17.24 Watts was obtained when temperature difference was -0.67^0C and minimum average power output of 5.73 Watts was obtained when temperature difference was 1.44^0C for 45 Watts rated Solar Panel.

Thus, Ambient and Solar panel's surface temperatures were considered to have significant influence on the output power produced by solar power system.

Patel (1999) expresses the temperature coefficients of Open-Circuit Voltage (Voc) and Short Circuit Current (Isc) of a typical single crystal Silicon Solar cells as 5mu per ^0C and 500µu per ^0C respectively.

It is therefore the objectives of this work to:

(i) determine the temperature coefficients of Open-Circuit voltage (V_{oc}) and Short-Circuit Current (I_{sc}) of typical Multi-crystalline Silicon Solar Cells.

(ii) quantify the effect of temperature difference of ambient temperature and solar panel's surface temperature on the output performance of the Solar power system.

Scientia Africana, Vol. 12 (No.1), June 2013. Pp57-66
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MATERIALS AND METHODS

Some materials were employed in taking measurements of empirical data. These include 45Watts Multi-Silicon Solar Panel with model STP045-12/Rb, 70Watts Multi-Silicon Solar Panel with model STP070-12/Rb, 0.5kVA Inverter, 100Ah Prostar Battery, manually fabricated Pole tracker, Digital Thermometer and Digital Multimeter.

The Solar Panel was mounted on a manual tracker system in October – November, 2008 and October-December, 2009. The trackers were positioned at eastern location (latitude 4^0 55' 58" North and longitude of 6^0 59' 55" East) 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:

$$P_{out} = I_{sc} \text{ x } V_{oc} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 2$$

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 3 is the equation for the efficiency of the inverter.

$$Efficiency = \frac{a.c.outputvoltage}{d.c.inputvoltage} \text{ X } 100 \quad \ldots\ldots\ 3$$

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

$$E = \frac{P_m}{\varepsilon \bullet A_s} \text{ x } 100\% \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ 4$$

Where: Ė = Efficiency of the energy conversion
P_m = Maximum Power Point
ε = Light Input irradiance (W/m^2)
A_s = Surface Area (m^2)

Figure 1 shows a typical structural part of a solar panel (www.visualdictionaryonline.com) placed in a frame. Figure 2 illustrates the experimental set-up.

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

REPRESENTATION OF THE SETUP

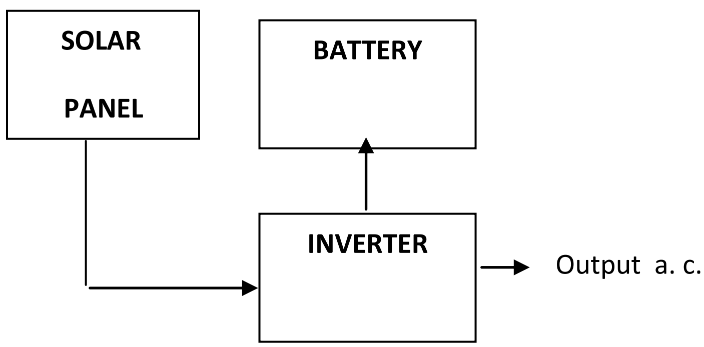

Fig. 2 : Block diagram of the experimental setup**.**

The coefficients of temperatures are determined through the followings:

$$I_{sc} = I_0(1+\alpha.\Delta T) \quad \text{……………………….. 5}$$

$$V_{oc} = V_0(1-\beta.\Delta T) \quad \text{…………………… 6}$$

Where :

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

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

α is the temperature coefficient of short-circuit current at reference temperature, T in per ^{0}C.

β is the temperature coefficient of open-circuit voltage at reference temperature, T in per ^{0}C.

$$P_{out} = I_{sc} x V_{oc} = I_0(1+\alpha.\Delta T) x V_0(1-\beta.\Delta T) \text{ …..7}$$

By ignoring a small term, $\alpha\beta(\Delta T)^2$, Equation 7 becomes :

$$P_{out} = P_o[1+(\alpha-\beta).\Delta T] \quad \text{……………..……8}$$

Table 1 shows the typical measured values for day 2 using 45 Watts Multi-Silicon cells and table 2 reveals the measured values for day 2 using 70 Watts Multi-Silicon cells.

Scientia Africana, Vol. 12 (No.1), June 2013. Pp57-66
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Table 1: The typical measured values for day 2 using 45 Watts Multi-Silicon cells

TIME	V(VOLTS)	I(AMPS)	P(WATTS)	Tatm(°C)	Tpan(°C)	Tp - Ta
7.00am	19.46	0.27	5.25	28	28	0
7.15am	19.62	0.32	6.27	28	28	0
7.30am	19.56	0.35	6.85	28	28	0
7.45am	20.06	0.55	11.03	28	29	1
8.00am	19.47	0.54	10.51	27	28	1
8.15am	20.05	0.69	13.83	27	28	1
8.30am	20.11	0.11	22.12	28	28	0
8.45am	19.56	0.35	6.85	31	28	-3
9.00am	19.82	0.4	7.93	32	29	-3
9.15am	20.34	1.67	33.97	34	30	-4
9.30am	19.46	0.69	13.43	35	32	-3
9.45am	17.74	0.57	10.11	36	32	-4
10.00am	20.52	1.05	21.55	37	33	-4
10.15am	20.06	1.13	22.67	36	32	-4
10.30am	20.2	1.69	34.14	36	32	-4
10.45am	18.27	0.89	16.26	35	31	-4
11.00am	19.81	2.09	41.4	38	32	-6
11.15am	19.67	2.07	40.72	36	32	-4
11.30am	19.79	2.64	52.22	36	32	-4
11.45am	13.36	0.7	9.35	36	32	-4
12.00pm	19.73	0.79	15.58	36	34	-2
12.15pm	19.37	1.13	21.89	35	34	-1
12.30pm	19.81	1.24	24.56	37	35	-2
12.45pm	19.7	1.2	23.64	35	39	4
1.00pm	19.73	1.61	31.77	35	35	0
1.15pm	19.36	0.72	13.94	34	34	0
1.30pm	19.47	0.48	9.35	32	31	-1
1.45pm	19.61	0.49	9.61	32	31	-1
2.00pm	20.12	0.77	15.49	34	33	-1
2.15pm	20.11	0.99	19.9	32	36	4
2.30pm	20.09	0.78	15.67	31	35	4
2.45pm	19.87	0.73	14.51	31	33	2
3.00pm	19.71	0.73	14.39	32	34	2
3.15pm	19.21	0.67	12.87	27	33	6
3.30pm	19.01	0.27	5.13	32	34	2
3.45pm	19.09	0.28	5.35	29	30	1
4.00pm	19.4	0.35	6.79	29	30	1
4.15pm	19.15	0.27	5.17	30	30	0
4.30pm	18.7	0.17	3.18	30	30	0
4.45pm	18.99	0.14	2.66	30	29	-1
5.00pm	18.46	0.12	2.22	28	29	1
5.15pm	18	0.08	1.44	28	30	2
5.30pm	17.44	0.02	0.35	29	27	-2
5.45pm	15.23	0.03	0.46	27	29	2
6.00pm	8.59	0.01	0.08	27	28	1
6.15pm	6.12	0	0	27	28	1
Average	**18.7173913**	**0.713913043**	**14.40130435**	**31.76087**	**31.19565**	**-0.565217391**

Table 2: The typical measured values for day 2 using 70 Watts Multi-Silicon cells

TIME	V(VOLTS)	I(AMPS)	Power (Watts)	Tatm(°C)	Tpan(°C)	Tp - Ta
7.30a.m	12.06	0.08	0.96	28	25	-3
7.45a.m	16.44	0.08	1.32	28	25	-3
8.00a.m	18.46	0.52	9.6	28	25	-3
8.15a.m	17.28	0.91	15.72	28	25	-3
8.30a.m	18.4	0.89	16.38	29	26	-3
8.45a.m	18.1	0.54	9.77	29	26	-3
9.00a.m	19.2	0.84	16.13	28	27	-1
9.15a.m	19.53	0.99	19.33	29	28	-1
9.30a.m	18.99	1.02	19.37	29	29	0
9.45a.m	19.42	0.47	19.13	30	30	0
10.00a.m	19.84	0.74	14.68	30	31	1
10.15a.m	19.13	1.32	25.25	31	32	1
10.30a.m	18.44	1.1	18.62	32	34	2
10.45a.m	17.34	2.01	34.85	33	37	4
11.00a.m	19.16	2.17	42.55	33	37	4
11.15a.m	19.92	2.06	41.03	33	41	8
11.30a.m	16.55	2.4	39.72	32	42	10
11.45a.m	19.91	2.48	49.38	33	47	14
12.00a.m	19.65	0.74	14.54	33	48	15
12.15a.m	19.42	2.01	39.03	33	49	16
12.30a.m	19.58	2	39.16	34	50	16
12.45a.m	19.52	2.04	39.82	33	50	17
1.00p.m	19.88	1.99	39.56	32	50	18
1.15p.m	19.82	1.52	30.13	34	47	13
1.30p.m	19.48	1.88	36.62	34	43	9
1.45p.m	19.36	1.93	37.36	31	47	16
2.00p.m	19.64	1.5	28.46	33	50	17
2.15p.m	19.87	1.84	36.56	31	45	14
2.30p.m	19.88	1.65	32.8	30	49	19
2.45p.m	19.98	1.54	30.77	29	46	17
3.00p.m	19.5	1.6	31.2	29	42	13
3.15p.m	19.78	1.51	29.87	28	43	15
3.30p.m	19.81	1.78	35.26	27	45	18
3.45p.m	19.92	1.68	33.46	27	47	20
4.00p.m	19.79	1.42	28.1	25	43	18
4.15p.m	19.88	1.35	26.84	23	41	18
4.30p.m	19.64	0.99	19.44	22	41	19
4.45p.m	19.64	0.99	19.44	21	39	18
5.00p.m	18.98	0.8	15.18	21	35	14
5.15p.m	18.23	0.82	14.95	21	31	10
5.30p.m	17.85	0.75	13.39	20	31	11
5.45p.m	17	0.52	8.84	21	32	11
6.00p.m	16.42	0.54	8.87	21	29	8
6.15p.m	13.84	0.18	2.49	20	27	7
6.30p.m	4.41	0.02	0.09	20	24	4
Average	**18.42088889**	**1.2491111**	**24.133778**	**28.35556**	**37.57778**	**9.222222**

Table 3 and 4 show the daily average measurements of 45Watts and 70 Watts solar panel respectively.

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Table 3: Daily average measurements for 45 Watts Solar Panel.

Days	Daily Average, Vo	Daily Average, Io	Daily Average, Power	Daily Average, ΔT = Tp-Ta	Daily Average, α	Daily Average, β
Day 1	18.10534884	0.273282856	7.792093023	-0.697674419	1.964719272	0.125575177
Day 2	18.7173913	0.713913043	14.40133044	-0.5652174	1.133295757	0.017888612
Day 3	18.956739	0.8713043	17.24130435	-0.673913043	1.200173717	0.017119995
Day 4	18.7226087	0.46717391	9.205652174	0.82608696	0.422719843	0.038888229
Day 5	18.71804	0.534783	11.01782609	1.652173913	1.311644184	0.049645043
Day 6	18.78848	0.55913	11.0973913	1.3695652	4.333846112	0.079102562
Day 7	18.69065	0.569783	11.27	1.7391304	2.338174531	0.059983867
Day 8	18.81848	0.672591	13.48565217	1.5652174	1.617866352	1.617866352
Day 9	18.28978	0.506739	9.904782609	1.5	2.383081698	2.383081698
Average	**18.64527976**	**0.574300012**	**11.71289246**	**0.746152112**	**1.856169052**	**0.487683504**

Table 4 : Daily Average measurements for 70 Watts Solar Panel.

Days	Daily Average, Vo	Daily Average, Io	Daily Average, Power	Daily Average, ΔT = Tp-Ta	Daily Average, α	Daily Average, β
Day 1	19.26688889	1.109111111	21.34266667	7.911111111	3.395503373	0.02678702
Day 2	18.42088889	1.249111111	24.13377778	9.222222222	1.905465412	0.054257119
Day 3	18.496	1.3444444	26.34222222	10.1333333	7.128273981	0.082126447
Day 4	17.7642222	1.16511111	22.20377778	9.511111111	-3.32868	-0.05433091
Day 5	18.16266667	1.188	23.05955556	10.62222222	3.063095073	0.058911542
Day 6	18.482	1.03422222	20.68844444	8.422222222	0.425782466	0.021751468
Day 7	19.07644444	1.398889	27.41955556	10.31111111	0.1015377	0.09956646
Day 8	18.47933333	1.343333	26.37911111	9	0.383204934	0.015807673
Average	**18.51855555**	**1.229027744**	**23.94613889**	**9.391666662**	**1.634272867**	**0.038109602**

DISCUSSION

The significance of temperature coefficients of open-circuit voltage (β) and short-circuit current (α) is to quantify the effect of temperature (ΔT= Tp-Ta) on the output performance of typical solar cells.

Tables 1, 2, 3, and 4 reveal the detailed results of the empirical data collected during the study. The overall average of α and β are determined as 1856mu/^{0}C and 488mu/^{0}C respectively for 45 Watts multi-silicon solar cell. Also, the overall average of α and β are determined as 1634mu/^{0}C and 38mu/^{0}C respectively for 70 Watts multi-silicon solar cell. The two results for different solar power rating of multi-silicon solar cells are compared favourably to each other.

It is observed that the temperature coefficients of short-circuit current (α) and open-circuit voltage (β) for multi crystalline silicon solar cell are far higher than that of typical single silicon solar cells as reported by patel,1999 (α =500µu/^{0}C and β = 5mu/^{0}C). This result could evidently shows one of the reasons why single crystalline silicon solar cells are more efficient in power output performance than the multi-crystalline solar cells. The temperature coefficients of single crystal silicon cells are lower than that of multi-crystalline silicon cells.

Equation 8 is considered in quantifying the effect of temperature coefficients on power output of typical 45 Watts Multi-silicon solar cell.

$\alpha = 1.856/^0C$ and $\beta = 0.488/^0C$

$$P = P_0[1 + (1.856 - 0.488)\Delta T]$$

$$P = P_0[1 + 1.386\Delta T]$$

For temperature difference between solar panel's surface temperature and ambient temperature:

$$P = P_0[1 + (1 + (1 - 0.632))\Delta T] \quad \ldots\ldots 9$$

For 70 Watts multi-crystalline silicon cells ,

$\alpha = 1.634/^0C$ and $\beta = 0.038/^0C$

$$P = P_0[1 + (1.634 - 0.038)\Delta T]$$

$$P = P_0[1 + 1.596\Delta T]$$

Hence, for temperature difference between solar panel's surface temperature and ambient temperature:

$$P = P_0[1 + [1 + (1 - 0.404)]\Delta T] \quad \ldots\ldots\ldots\ldots\ldots\ldots 10$$

Equation 9 indicates that for every ^0C rise in the operating temperature above the ambient temperature of 45 Watts multi-silicon solar cells, the silicon output power decreases by 63%.

Equation 10 also shows decrease in power output by 40% for 70 Watts multi-silicon solar cells at every ^0C rise in operating temperature. Thus, at high operating temperature, the power output decreases.

It is also observed that there is a very high percentage of power loss in multi-silicon solar cells for every ^0C rise in operating temperature when compared with 0.45% loss of single crystal silicon cell as reported by Patel, 1999.

Figure 3 and 4 show the characteristic curves of α and β when temperature changes for 45 Watts and 70 Watts Solar cells respectively.

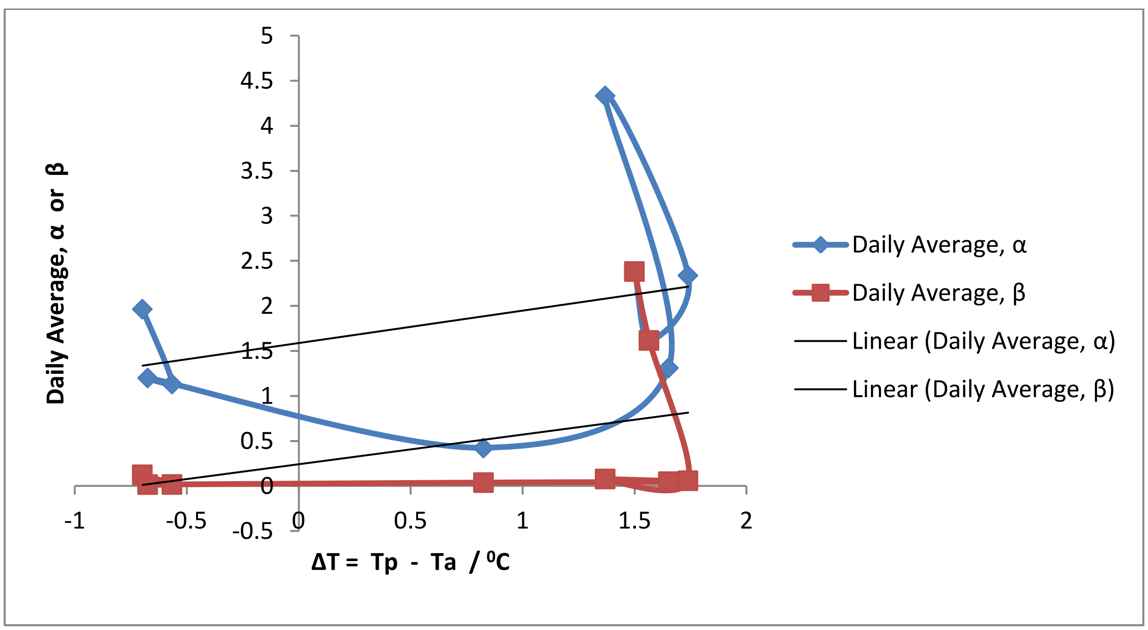

Fig. 3 : Graph of Daily Average α and β versus temperature change, ΔT for 45 Watts Multi-crystalline Silicon Solar cells.

Scientia Africana, Vol. 12 (No.1), June 2013. Pp57-66

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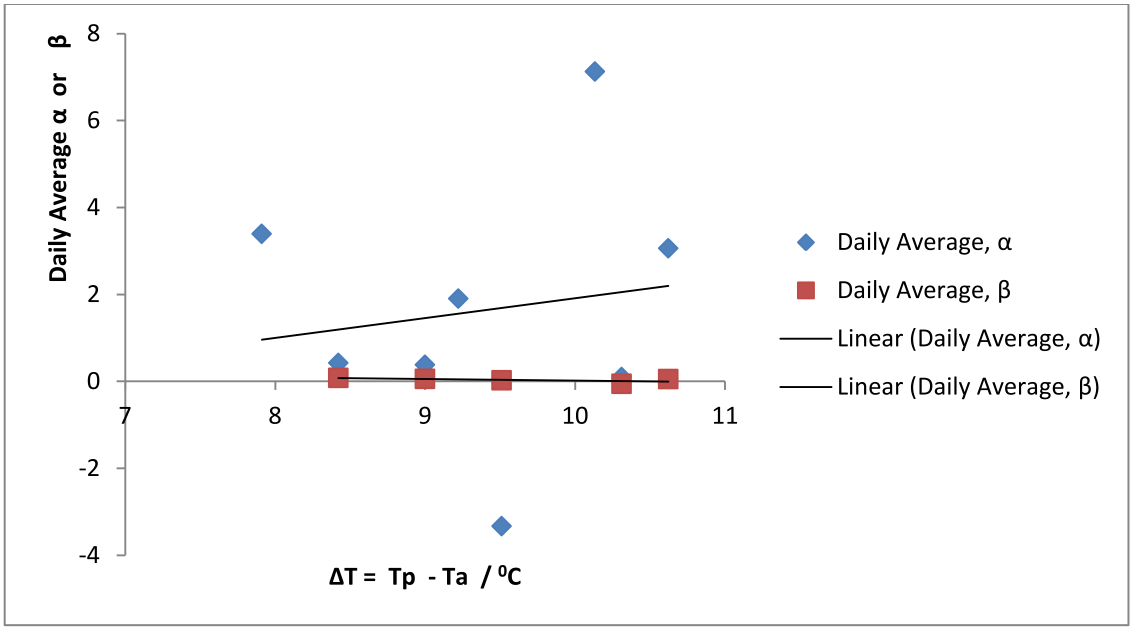

Fig. 4 : Graph of Daily Average α and β versus temperature change, ΔT for 70 Watts Multi-crystalline Silicon Solar cells.

CONCLUSION

Temperature coefficients of short-circuit current (α) and open-circuit voltage (β) were determined from measured data.

The power output of multi-crystalline silicon solar cells decreases by every ^{0}C rise in temperature above the operating temperature.

Typically, multi-crystalline silicon solar cells rated 45 Watts power output decreases by 63% while 70 Watts power output decreases by 48% for every ^{0}C rise in operating temperature.

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