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Effects of Angles of Inclinations on the Performances of Photovoltaic (PV) Arrays

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Abstract- Photovoltaic (PV) has gained a lot of attention from government, private investors and individual due to epileptic power supply in the cities and rural areas. The performance of 50W mono crystalline and 50W poly crystalline at different tilt angles were carried out in this work to know particular angle of inclination to get optimum performance from solar panels at a given geographic location. A data acquisition system is designed using PIC18F4550 microcontroller to acquire, process and store data for further analysis. Ambient temperature and electrical parameters of each PV module includes open circuit voltage, load voltage and load current were experimentally determined for some days between 9:00am and 5:00 pm at The Federal Polytechnic Ede (Latitude 7°44'20"N, Longitude. 4°26'10"E and 307 metres above sea level) simultaneously at different tilt angles. The obtained experimental data were used for power calculation and analysis. The maximum electrical energy generation is obtained at angle 30^0 and best result was obtained at 0^o angle of inclination at 12.00 noon for both solar panels. The output of both solar panels depends on sun position and relative position of solar panel.

Keyword: Geographic location, microcontroller, Photovoltaic, solar radiation, tilt angle.

1.0 Introduction

Renewable energy sources are getting more attention as the world is facing problem of energy deficit and bad consequences of fossil fuels (Dinesh, Sunil, and Jayashree, 2014). An attractive method of power generation that meets the criteria of clean energy and sustainability is provided by Photo Voltaic (PV) technology (Roscia and Zaninelli, 2002). PV modules have many applications for electricity generation in remote, rural, and urban areas and different sectors of economy ranging from agriculture, household to industry (Ankita and Tiwari, 2013) and healthcare system.

In order to get the most from solar panels, there is need to point them in the direction that captures the most sun radiation. Best practice advocated by several authors is that the tilt angle should be equal to the latitude plus 15^0 in winter or subtraction of 15^0 in the summer (Naganagouda, 2015). Solar cells generate electromotive force as a result of absorption of ionizing radiation. Absorbed energy is associated with the photons of sunlight and it is related to wavelength by equation (1).

$$E = \frac{hc}{\lambda} \tag{1}$$

where h is plank's constant$= 6.62x10^{-34}js$, c is the velocity of light $= 3x10^8 m/s$ and λ is the wavelength. The equivalent circuit of the solar cells is combination of a current source (light generated current) and a diode as shown in Figure 1. The basic equations for solar cells are as shown in equations (2) and (3) (Lindholm, Fossum, and Burgess, 1979).

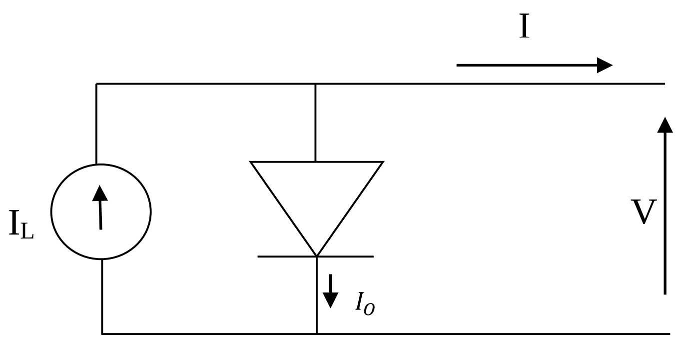

Figure 1: Solar cell equivalent circuit

$$I = I_O \left[exp\left(\frac{qV}{nkT}\right)\right] - I_L \quad (2)$$

$$V_{oc} = \frac{nkT}{q} ln\left[\frac{I_L}{I_O} + 1\right] \quad (3)$$

where I_L is light generated current, I_O is dark saturation current, that is, the diode leakage current density in the absence of light, I is the net current flowing through the diode and V is the applied voltage across the terminals of the diode.

Photo current or light generated current, mainly depends on the solar insolation and cell working temperature (Ami, Manju, and Shukla, 2015). Therefore, tilt angle and direction faced by solar panel is important in order to get the most from solar panels. This research focuses on how PV can optimize the production of electrical energy through tilt angle such that incident solar irradiance will be well utilized.

2.0 Methodology

This research aims to evaluate the performance of mono crystalline and poly crystalline solar technologies when tilted at various angle of inclination under the same weather conditions. Experimental setup and its block diagram are as shown in Figures 2 and 3 respectively. The test bed consists of a table with adjustable support to vary angle of inclination, 50W mono crystalline and 50W poly crystalline solar panels, sensors, data acquisition based on PIC18F4550 microcontroller, display and Personal Computer (PC).

PIC18F4550 microcontroller has 10-bit inbuilt Analog to Digital Converter (ADC) and it is used to acquire, analyze and process the output of various sensors. The ADC reports a **ratiometric value**. and it has value in range of 0-1023. This means that the ADC assumes 5V is 1023 and anything less than 5V will be a ratio between 0 and 1023. Therefore, equation (4) gives the output of any sensor used when fed to ADC.

$$\frac{ADC\ reading}{analog\ Voltage\ measured} = \frac{1023}{5} \quad (4)$$

Measured solar currents, voltages and temperature are displayed on LCD and also stored in a secure digital (SD) card for further analysis.

Figure 2: Experimental set-up

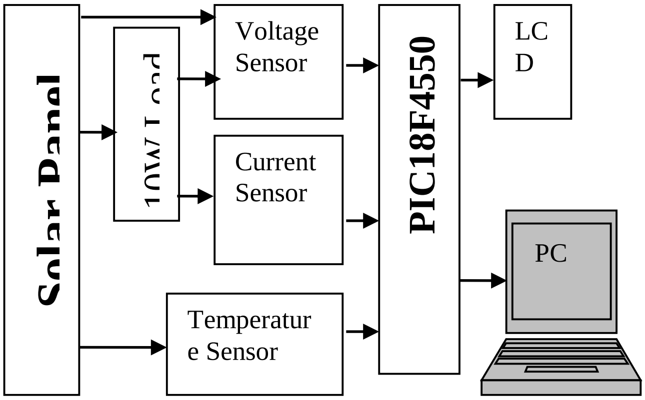

Figure 3: Block diagram of experimental set-up

2.1 Experimentation

The experiment was performed at The Federal Polytechnic Ede, Osun State, Nigeria (Latitude of 7°44′20″N, Longitude. 4°26′10″E and 307 metres above sea level). The solar modules were first laid flat on the table such that they were parallel to the horizontal plane and latter tilted at approximately 10^o, 20^o, 30^o and 40^o to the horizontal.

Instantaneous capturing, measuring and storing of open circuit voltage, load voltage, current of both panels and temperature were carried out using data acquisition system at intervals of 10 seconds from 9:00 am to 5:00 pm daily and displayed as shown in Figure 4. Data captured were downloaded to personal computer every evening for further analysis.

3.0 Results and Discussion

Experimental measured parameters are displayed in Figure 4 and data downloaded for various angles of inclination are also listed in Tables 1 to 5.

Figure 4: LCD displaying instantaneous measured parameters.

Table 1: Data recorded at 0^0 angle of inclination

Time	T (^oC)	P OV	PLV	PI	PPW	MOV	MLV	MI	MPW
9:00	51	19.2	16.7	1.86	31.06	19.1	16.2	1.91	13.94
10:00	51	19.2	16.7	1.88	31.39	19.1	16.1	1.96	31.56
11:00	46	19.3	15.9	1.92	30.53	19.1	16.2	1.93	29.34
12:00	42	20.0	18.0	2.04	36.72	19.7	17.3	2.09	36.16
13:00	52	19.1	17.0	1.95	33.15	19.1	16.3	2.06	33.58
14:00	42	20.1	16.7	1.91	31.89	19.0	16.3	2.04	33.25
15:00	38	18.6	0.4	0.40	0.16	18.5	0.40	0.40	0.16
16:00	35	18.6	0.2	0.27	0.05	18.3	0.20	0.27	0.05
17:00	35	18.7	0.3	0.32	0.09	18.5	0.30	0.33	0.09

Table 2: Data recorded at 10^0 angle of inclination

Time	T (^oC)	POV	PLV	PI	PPW	MOV	MLV	MI	MPW
10:00	38	19.7	9.1	1.43	13.01	19.6	8.5	1.47	12.49
11:00	38	19.6	7.7	1.31	10.09	19.5	7.5	1.34	10.05
12:00	43	19.4	11.9	1.69	20.11	19.4	11.5	1.71	19.67
13:00	42	18.8	3.8	0.95	3.61	18.7	4.1	0.97	3.98
14:00	40	19.0	10.3	1.40	14.42	18.5	10.1	1.43	14.44
15:00	37	19.5	7.6	0.72	5.47	19.0	7.4	0.75	5.55
16:00	33	18.9	0.5	0.51	0.26	18.7	0.4	0.55	0.22
17:00	29	19.1	0.3	0.35	0.11	18.0	0.1	0.39	0.04

Table 3: Data recorded at 20^0 angle of inclination

Time	T(^oC)	POV	PLV	PI	PPW	MOV	MLV	MI	MPW
9:00	31	19.8	5.2	1.07	5.56	19.8	4.4	1.08	4.75
10:00	31	19.8	5.2	1.07	5.56	19.8	4.4	1.08	4.75
11:00	37	19.9	14.2	1.71	24.28	19.8	12.4	1.73	21.45
12:00	41	19.7	16.8	1.87	31.42	19.6	16.2	1.92	31.10
13:00	43	19.2	6.1	1.11	6.77	18.9	18.8	0.03	0.56
14:00	48	19.6	10.8	1.45	15.66	19.4	19.3	0.04	0.27
15:00	43	19.1	2.7	0.80	2.16	19.0	18.9	0.02	0.38
16:00	39	19.3	1.4	1.63	0.88	19.3	19.2	0.01	0.19
17:00	30	19.6	0.1	0.19	0.02	18.3	18.3	0.00	0.00

Table 4: Data recorded at 30^0 angle of inclination

Time	T(^oC)	POV	PLV	PI	PPW	MOV	MLV	MI	MPW
9:00	29	19.7	1.6	0.66	1.06	19.7	19.6	0.01	0.20
10:00	32	20.0	7.2	1.19	8.60	20.0	20.0	0.03	0.60
11:00	39	19.4	4.8	1.00	4.80	19.3	19.2	0.02	0.38
12:00	37	19.6	4.6	0.97	4.46	19.6	19.5	0.02	0.39
13:00	47	19.9	17.7	1.87	33.10	19.8	19.7	0.06	1.18
14:00	48	19.7	14.4	1.66	23.74	19.4	19.3	0.05	0.97
15:00	47	19.6	4.3	0.96	4.13	19.3	5.6	1.12	6.27
16:00	40	19.2	0.5	0.44	0.22	19.0	0.6	0.46	0.80
17:00	38	18.6	0.1	0.21	0.02	18.3	0.1	0.21	0.02

Table 5: Data recorded at 40^0 angle of inclination

Time	T(^oC)	POV	PLV	PI	PPW	MOV	MLV	MI	MPW
9:00	46	19.7	17.3	1.88	32.52	19.6	16.8	1.93	32.42
10:00	45	19.3	16.7	1.87	31.54	19.6	16.5	0.95	33.35
11:00	46	19.2	17.1	1.80	33.50	19.7	16.2	1.94	34.02
12:00	47	20.0	17.8	1.94	34.53	19.9	17.3	1.97	34.08
13:00	49	20.0	17.1	1.89	32.32	19.9	16.5	1.94	32.01
14:00	55	19.4	11.5	1.53	17.59	19.2	10.6	1.55	16.43
15:00	48	19.3	2.9	0.82	2.38	19.2	2.3	0.81	1.86
16:00	40	19.0	0.6	0.48	0.29	18.8	0.6	0.49	0.29
17:00	31	18.5	0.1	0.19	0.02	18.1	0.1	0.20	0.02

POV: Poly crystalline Open Circuit Voltage, PLV: Poly crystalline Load Voltage, PI: Poly crystalline Load Current, PPW: Poly crystalline Power, MOV: Mono crystalline Open Circuit Voltage, MLV: Mono crystalline Load Voltage, MI: Mono crystalline Load Current, MPW Mono Crystalline Power

Actual data obtained for each module was applied to investigate the effect of the ambient temperature and angle of inclination on the performance of the module. Analysis of the electrical parameters (open circuit voltage) of each panel with respect to the temperature and angle of inclination was performed. The variation of solar open circuit voltage with respect to ambient temperature for considered angles of inclination during the test days are as shown in Figures 5 to 9.

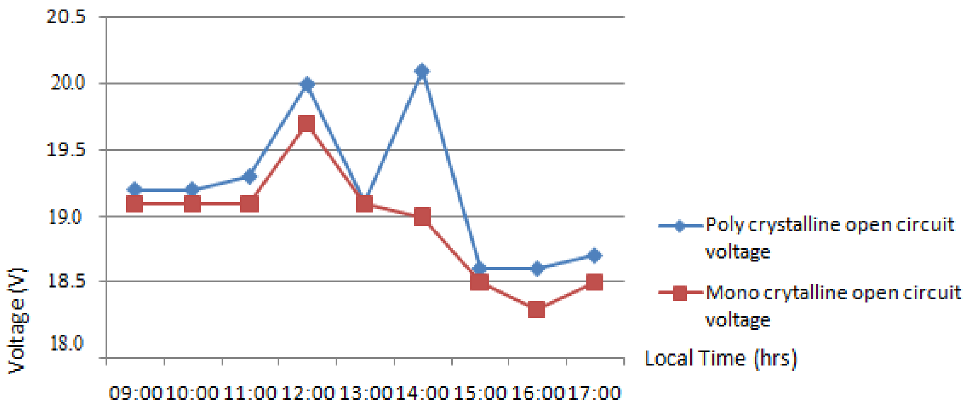

Figure 5: Open circuit voltage / temperature at 0^0 angle of inclination

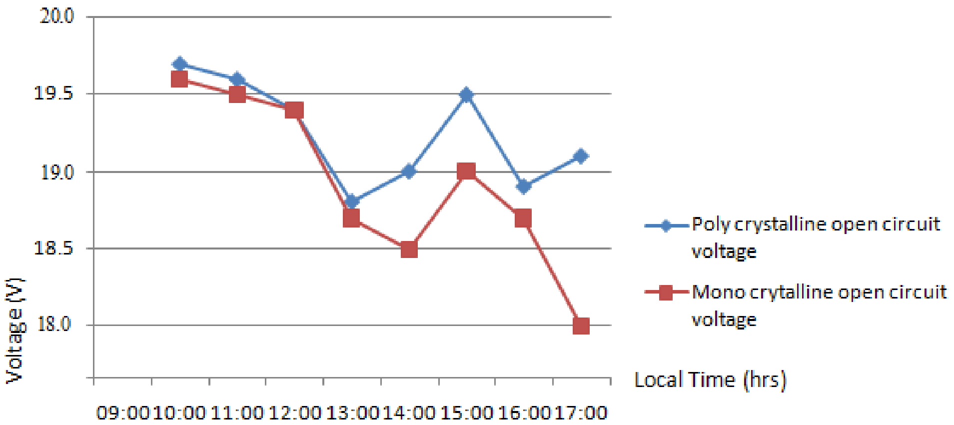

Figure 6: Open circuit voltage / temperature at 10^0 angle of inclination

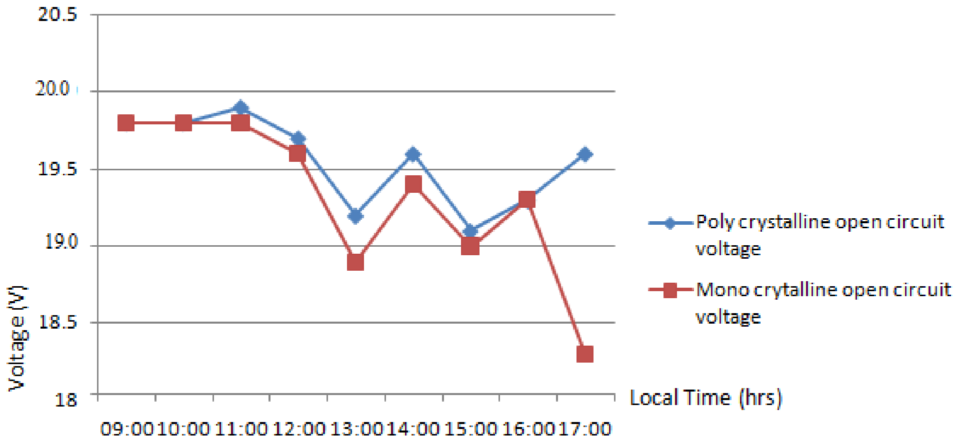

Figure 7: Open circuit voltage / temperature at 20^0 angle of inclination

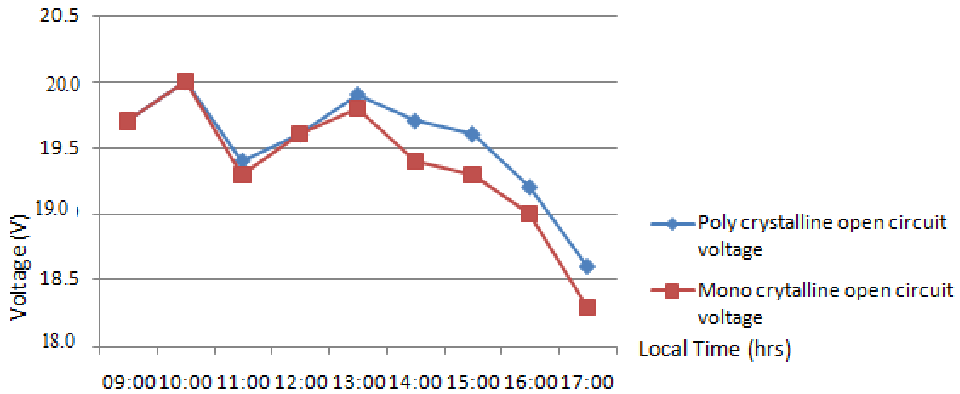

Figure 8: Open circuit voltage / temperature at 30^0 angle of inclination

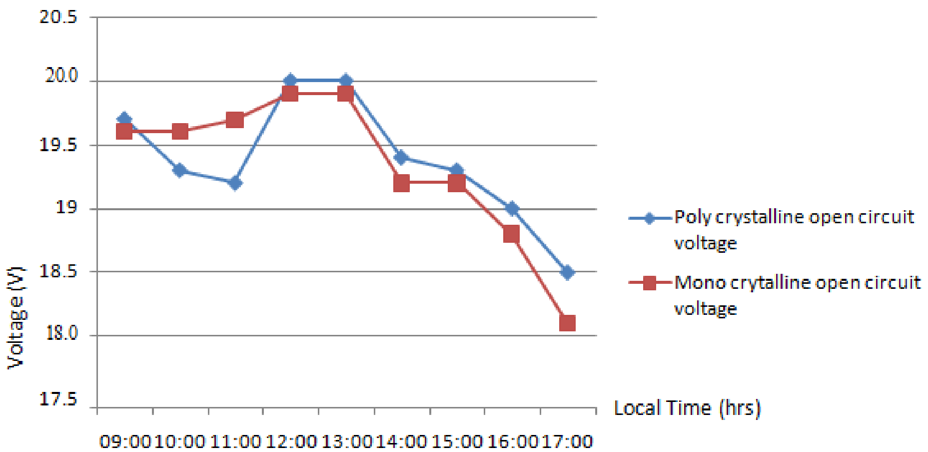

Figure 9: Open circuit voltage / temperature at 40^0 angle of inclination

The variation of solar open circuit voltage with respect to angles of inclination at particular temperature during the test days are is shown in Figures 10 to 14.

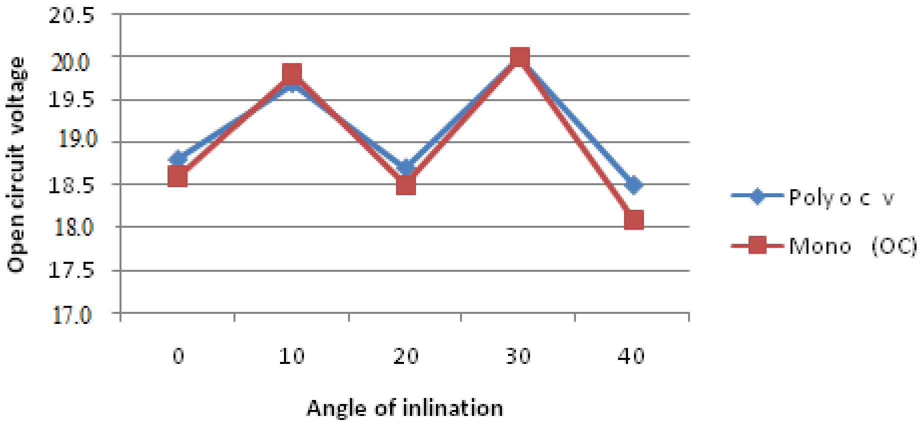

Figure 10: Open circuit voltage /angles of inclination at 30^0C

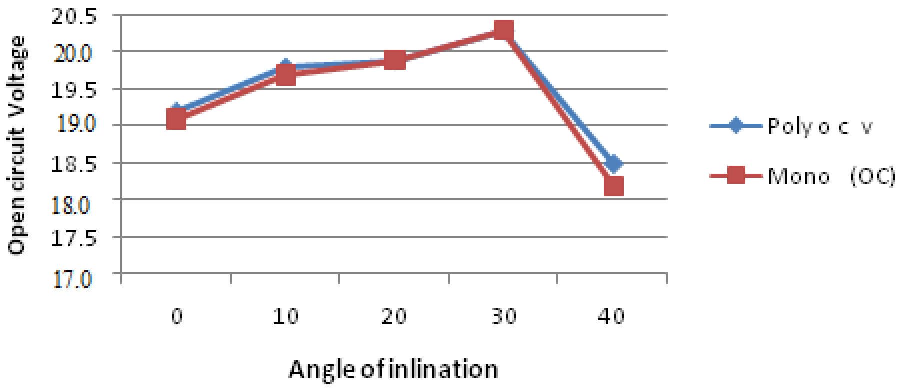

Figure 11: Open circuit voltage /angles of inclination at 35^0C

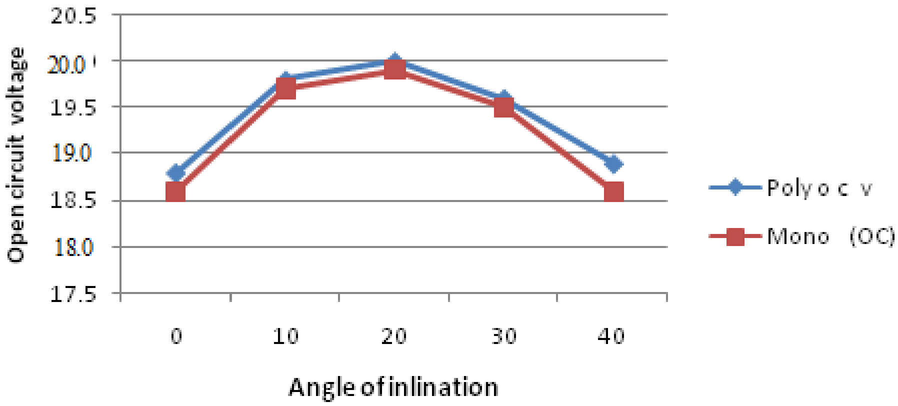

Figure 12: Open circuit voltage /angles of inclination at 40^0C

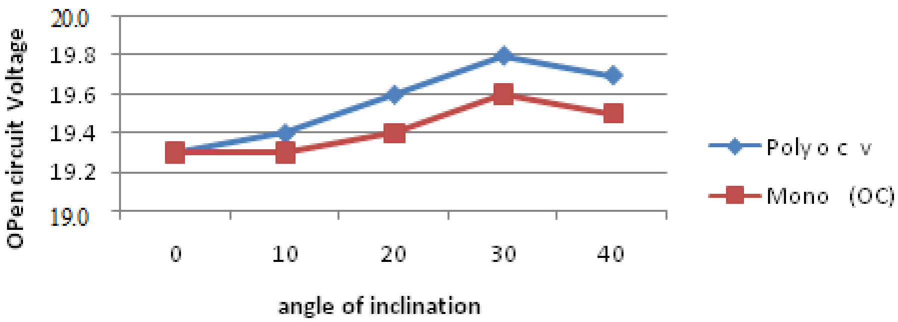

Figure 13: Open circuit voltage /angles of inclination at 45^0C

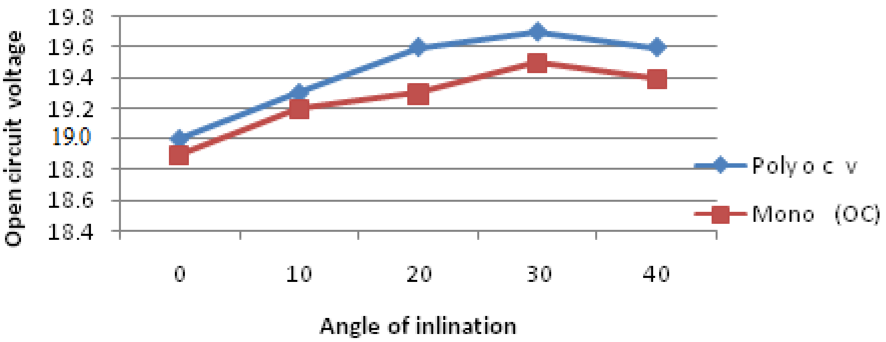

Figure 14: Open circuit voltage /angles of inclination at 50^0C

Fluctuations of ambient temperature led to fluctuations of output voltage of the two panels. Output voltages are very low during 9:00 am to 10:00 am and 3.00 pm to 5.00 pm. The maximum output voltage was obtained with 0^o angle of inclination at 12:00 noon because the sun ray was perpendicular to the panels. Also, the poly crystalline solar panel gave higher output voltage compared to mono crystalline at the same given temperature.

4 Conclusion and Recommendation

In this study, a comprehensive conversion of solar radiation to electrical energy analysis of poly crystalline and mono crystalline solar PV module at different tilt angle is conducted experimentally. It is seen from the research that both PV modules have a high energy conversion rate when inclined at 30^0 and best result was obtained with 0^o angle of inclination at 12.00 noon. The output of both solar panels depends on sun position and relative position of solar panel. Also, poly crystalline solar panel gave higher output voltage compared to mono crystalline at the same given temperature. Therefore, an effective solar tracking system is hereby recommended for optimum performance of solar panel.

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