Analysis of The Impact of Environmental Factors on Efficiency of Different Types of Solar Cells

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Abstract

Solar energy is pollution free and is abundantly available. Solar energy utilizes sunlight to give heat, light, electricity, etc. for domestic and industrial uses. With the alarming reduction of major energy resources such as coal, petroleum and gas, combined with the environmental deprivation caused by the process of harnessing these energy sources, it has become a necessity to capitalize renewable energy resources that would power the future energy needs adequately without degrading the environment through greenhouse gas release. Commercially available solar cells have efficiencies in the range 10-20%. Although recent breakthrough in the technology of solar cells shows significant improvement but the fact that the maximum solar cell efficiency still falls in the less than 20% range shows there is huge room for improvement. Mathematical models of the three types of solar cells (Monocrystalline, Polycrystalline and Thin film) were simulated using MATLAB. The values of irradiance and Temperature were varied and the effect of these in the efficiency of the solar cell was seen. Then an accumulative effect was seen which shows the effect of wind on the efficiency of solar cell. The data of different cities of Balochistan was also simulated and the results were seen. It was seen in this research that the temperature and irradiance affect the efficiency of the solar cell a lot and that the thin film solar cell is the most temperature tolerant solar cell.

Keywords: Solar cell Efficiency, mathematical model, irradiance, wind, temperature.

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INTRODUCTION

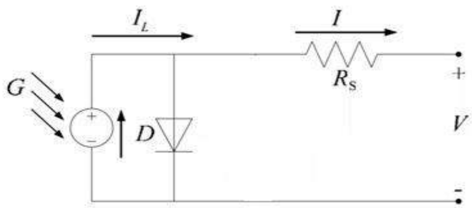
Most abundant and pollution free energy is solar energy. It utilizes sunlight to give heat, bright light and electricity to industrial and domestic users (Henry, 2013). With the disturbing decrease of conventional energy resources such as coal and petroleum it has become a requirement to take advantage of renewable energy resources that would provide the energy needs of the future adequately without degrading the environment through greenhouse gas release. The sun has immense energy potential, but due to a reduced amount of efficiency of the cells it is mainly a difficult task to extract electricity from it. This research is focused on finding the effect of different environmental parameters on the efficiency of solar cell. It uses a mathematical model which is simulated in MATLAB for different conditions of environment. Different solar cells perform differently under same environmental conditions. This research will help in ensuring that the optimal type of solar cell based panel is used in Pakistan that will be efficient.

Irradiance, wind speed and temperature of cell are the parameters on which complete performance of the solar cell depends. The parameters which are affected by the temperature are open circuit voltage, short circuit current and maximum power. But, open circuit voltage is affected mostly. The open circuit voltage changes very much with the temperature of the cell. It decreases with rise in temperature whereas short circuit current rises (Subash, 2015).

METHODOLOGY:

Mathematical Model:

A current source in parallel with a diode is the most common and simplest equivalent circuit of a solar cell. The more light falls on the cell the more current is produced from the output source (photocurrent I_L). When no light falls on the cell it produces no current and no voltage and works just like a diode. However, when it is connected to an external voltage source it generates diode current I_d. The diode determines the I-V characteristics of the cell.



Given by (Rekioua, 2012) the model of the solar cell is:

$$I = I_L - I_d \tag{1}$$

$$I = I_L - I_0\left(e^{\frac{q(V+IR_S)}{nkT}} - 1\right) \tag{2}$$

I_0 is the reverse saturation current which is defined by (6).

$$I_L = I_L(T_1) + K_0(T - T_1) \tag{3}$$

$$K_0 = \frac{I_{SC}(T_2) - I_{SC}(T_1)}{T_2 - T_1} \tag{4}$$

$$I_L(T_1) = I_{SC}(T_1, G_{nom})\frac{G}{G_{nom}} \tag{5}$$

$$I_0 = I_0(T_1)x\left(\frac{T}{T_1}\right)^{3/n} e^{\frac{qV_q(T_1)}{nk(\frac{1}{T}-\frac{1}{T_1})}} \tag{6}$$

$$I_0(T_1) = \frac{I_{SC}(T_1)}{\left(e^{\frac{qV_{OC}(T_1)}{nkT_1}} - 1\right)} \tag{7}$$

A series resistance R_s was included which shows resistance inside each cell in the connection between cells. This model assumes the shunt resistance as infinite and thus neglects it (Rekioua, 2012).

$$R_S = -\frac{dV}{dIV_{OC}} - \frac{1}{X_V} \tag{8}$$

$$X_V = I_0(T_1)\frac{q}{nkT_1}e^{\frac{qVoc(T_1)}{nkT_1}} \tag{9}$$

Data for Monocrystalline Silicon Solar Cell:

The data used for the simulation of monocrystalline silicon solar cell is taken from the data sheet of Sunpower's A300 monocrystalline silicon solar cell. The cell has the following electrical parameters. The value of K_o is 0.0035 °C/Wm^{-2} (Gonzalez, 2005).

Open Circuit Voltage	0.665V
Short Circuit Current	5.75A
Maximum Power Voltage	0.560V
Maximum Power Current	5.35A
Rated Power	3.0W
Efficiency	20%

This data of cell will be simulated on MATLAB with different values of temperature and different values of Irradiance. The temperature will be held constant on 25 degrees Celsius and the value of irradiance will be changed from 1000W/m^2 to 250W/m^2. Similarly, the temperature will be changed from 25 degrees Celsius to 55 degrees Celsius with irradiance constant at 1000W/m^2. To check an accumulative effect, the temperature and irradiance will be varied to depict an effect of wind on the solar cell. Maximum power will be noted in all these scenarios and will be used to check the efficiency of the solar cell.

Data for Polycrystalline Silicon Solar Cell:

A similar model will be used for polycrystalline silicon solar cell. The electrical parameters used will be changed and will be taken from the Sc origin polycrystalline SPM050-P data sheet. The cell has the following electrical parameters. The value of K_o is 0.0035 °C/Wm^{-2}.

Open Circuit Voltage	0.604V
Short Circuit Current	3.37A
Maximum Power Voltage	0.509V
Maximum Power Current	3.1A
Rated Power	1.52W
Efficiency	16%

This data will be simulated on MATLAB with a similar approach. The values of irradiance will be changed to different values and temperature will be held constant. Then another simulation will change the values of temperature where irradiance will be held constant. In an accumulative approach the values of temperature and irradiance will be changed showing the effect of wind on polycrystalline silicon solar cell.

Model for Thin Film Solar Cell:

The values of some constants will be different in the model of thin film solar cell. The diode ideality factor (n) will be less than two in the thin film mathematical model and energy gap for thin film solar cell will be 1.75eV whereas for crystalline it is 1.12eV (Rekioua, 2012). The electrical parameters of thin film Amorphous Silicon solar cell were taken from Sanyo Amorton Film data sheet which are given below in the table.

Open Circuit Voltage	0.890V
Short Circuit Current	14.8mA
Maximum Power Voltage	0.70V
Maximum Power Current	11.42mA
Rated Power	8mW
Efficiency	12.5%

Monthly Average Solar Radiation and Temperature of Sibi:

Monthly average solar radiation of Sibi is shown below in the table. The maximum solar radiation is 590W/m^2 which falls in June and the average day length is 13.8 hours whereas the minimum solar radiation is 342W/m^2 which falls in December and the day length is 10.4 hours.

This radiation data will be simulated in MATLAB using the model we developed earlier and the efficiency will be found out. This efficiency will be compared to the different types of solar cells.

Monthly Average Solar Radiation and Temperature of Dera Bugti:

Monthly average solar radiation of Dera Bugti is shown below in the table. The maximum solar radiation is 610W/m^2 which falls in July and the average day length is 13.1 hours whereas the minimum solar radiation is 314W/m^2 which falls in November and the day length is 9.9 hours.

Month	**Average Daily Radiation on a Horizontal Surface (W/ m^2)**	**Average Day Length (Hours)**
January	380	10.4
February	423	11
March	497	11.8
April	550	12.7
May	564	13.4
June	590	13.8
July	559	13.6
August	537	13
September	524	12.2
October	514	11.3
November	384	10.6
December	342	10.2
Average	489	12

Month	**Average Monthly Temperature (^{o}C)**
January	22.3
February	25.3
March	31.9
April	37.4
May	42.9
June	46.0
July	42.9
August	41.4
September	40.2
October	37.1
November	30.4
December	24.6

Month	**Average Daily Radiation on a Horizontal Surface(W/ m^2)**	**Average DayLength (Hours)**
January	410	9.2
February	390	10
March	460	12
April	540	12.8
May	580	12.5
June	570	13
July	610	13.1
August	555	13.8
September	570	12.5
October	504	11
November	314	9.9
December	442	10
Average	496	12

Month	**Average Monthly Temperature (^oC)**
January	19.6
February	22.7
March	28.7
April	34.5
May	39.6
June	41.7
July	39.1
August	37.3
September	36.4
October	33.5
November	27.5
December	22.1

RESULTS AND DISCUSSION

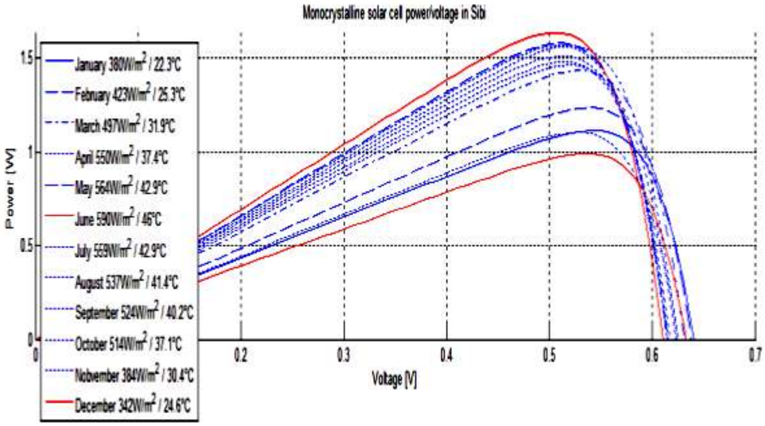


Figure 1: Monocrystalline solar cell simulated with Sibi data

As temperature and irradiance affects the solar cell efficiency a lot, both reducing the maximum power of the solar cell. Different Powers were observed from the simulation result. Maximum power was observed when the irradiance was maximum and minimum power of the cell was observed when the irradiance was lowest.

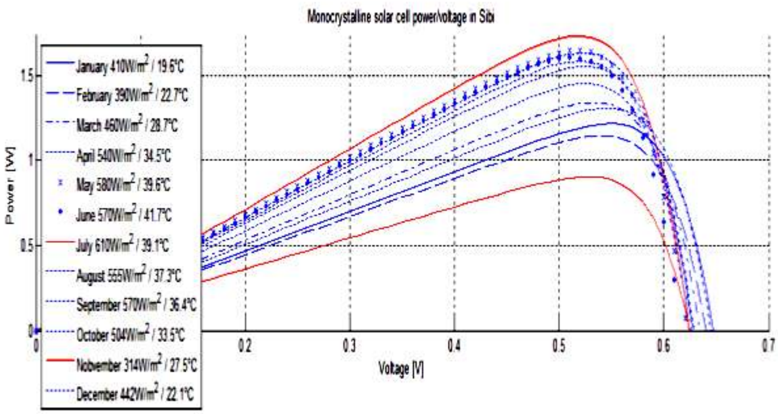


Figure 2: Monocrystalline solar cell simulated with Dera Bugti data

The maximum value of irradiance of Dera Bugti is more than Sibi therefore the maximum power of mono crystalline is more in Dera Bugti as the temperature is also lower than Sibi. Monocrystalline solar cell works better in Dera Bugti than Sibi according to this simulation.

The polycrystalline solar cell was affected by temperature more and the maximum power was reduced very much. As Sibi is a hot region the maximum power was reduced very much.

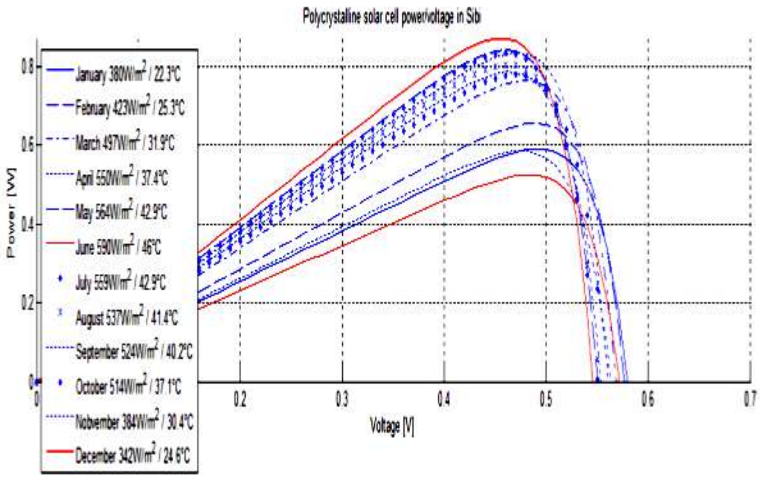


Figure 3: Polycrystalline solar cell simulated with Sibi data

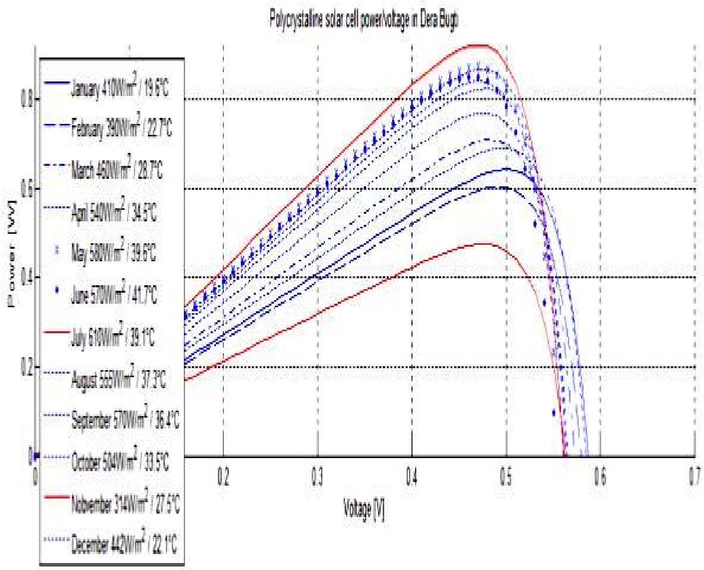


Figure 4: Polycrystalline solar cell simulated with Dera Bugti data

The maximum power of polycrystalline simulated with Dera Bugti data was better than Sibi because of the temperature difference between the two cities. Dera Bugti has better temperature than Sibi so the maximum power was more than Sibi.

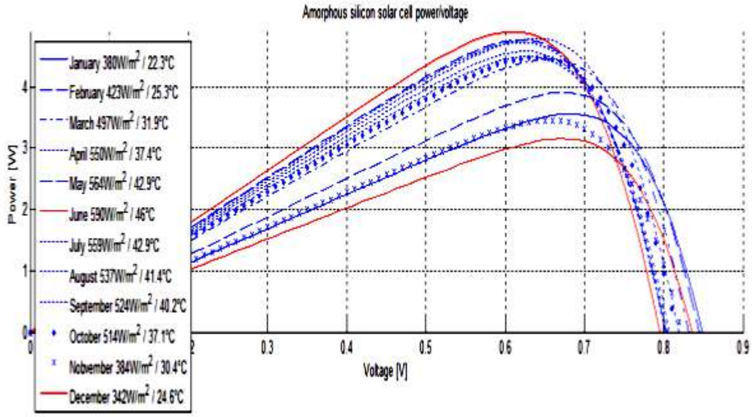


Figure 5: Thin Film Solar cell simulated with Sibi data

The maximum power of the thin film solar cell was reduced due to the increasing temperature and the reduction in irradiance similarly like other solar cells.

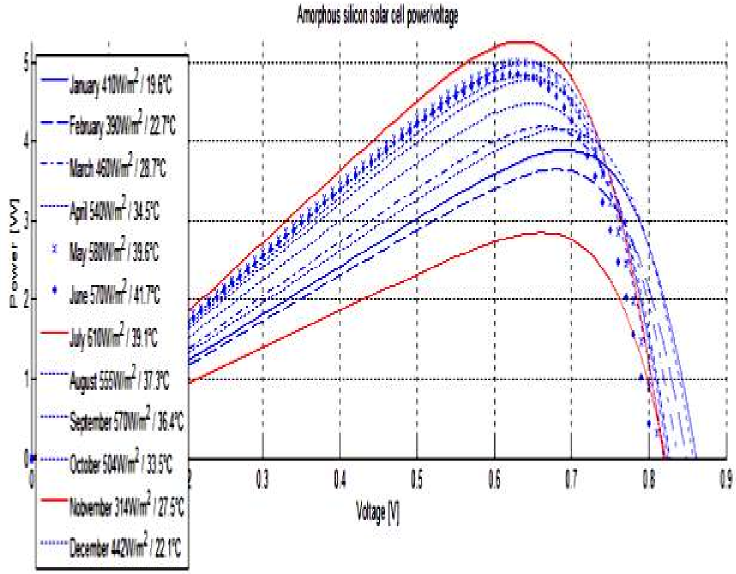


Figure 6: Thin Film Solar cell simulated with Dera Bugti data

The maximum power of the thin film solar cell in Dera Bugti was better than Sibi as the temperature is not low enough and the irradiance was more than Sibi.

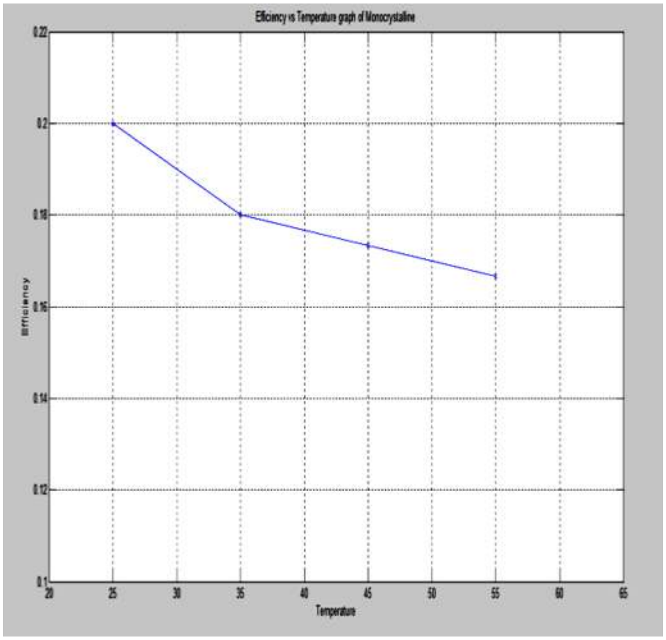


Figure 7: Efficiency of Monocrystalline with varying Temperature

The efficiency of monocrystalline solar cell reduces with increase in temperature. It is maximum at 25°C and reduces with increase in temperature. The efficiency first reduced more from 25 °C to 35 °C but then reduced linearly from 35 °C to 55 °C. The lowest efficiency was 16.5% at 55 °C and the maximum efficiency was 20% at 25 °C.

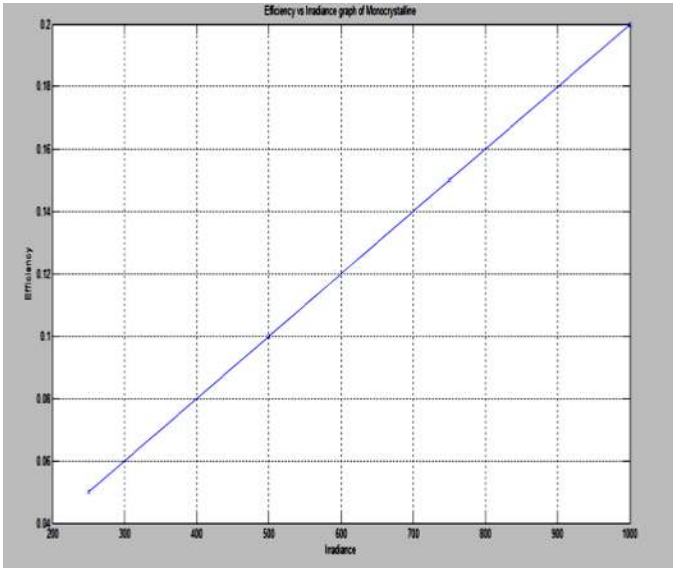


Figure 8: Efficiency with Irradiance of MonoCrystalline silicon solar cell

The efficiency of monocrystalline solar cell increases linearly with increase in irradiance. Maximum efficiency of 20% was observed at 1000W/m^2 whereas the efficiency reduces with reduction in irradiance. The efficiency was only 5% at 250W/m^2.

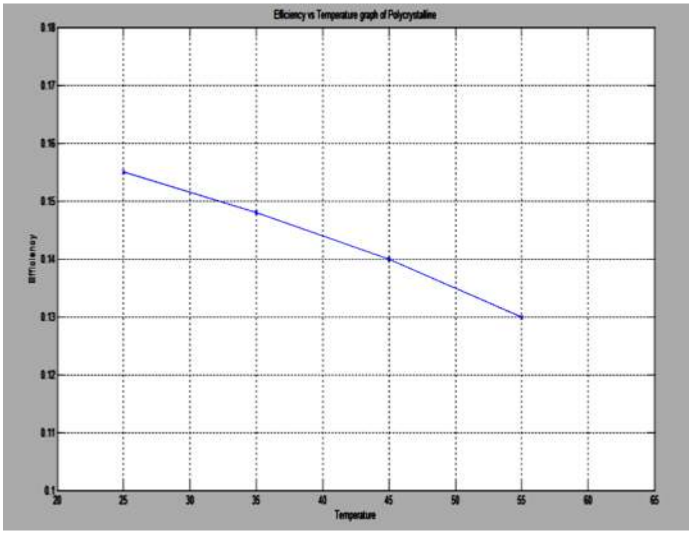


Figure 9: Efficiency with Temperature Polycrystalline silicon solar cell

The efficiency of Polycrystalline silicon solar cell also reduces with increasing temperature. But the rate of reduction is more than monocrystalline silicon solar cell. The maximum efficiency of polycrystalline silicon solar cell is 16.5% at 25 ^{o}C which reduces to 12% at 55 ^{o}C.

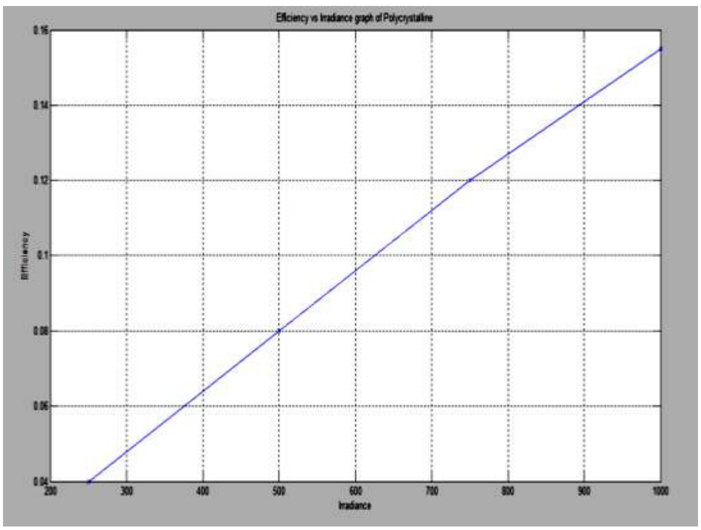


Figure 10: Efficiency with Irradiance Polycrystalline silicon solar cell

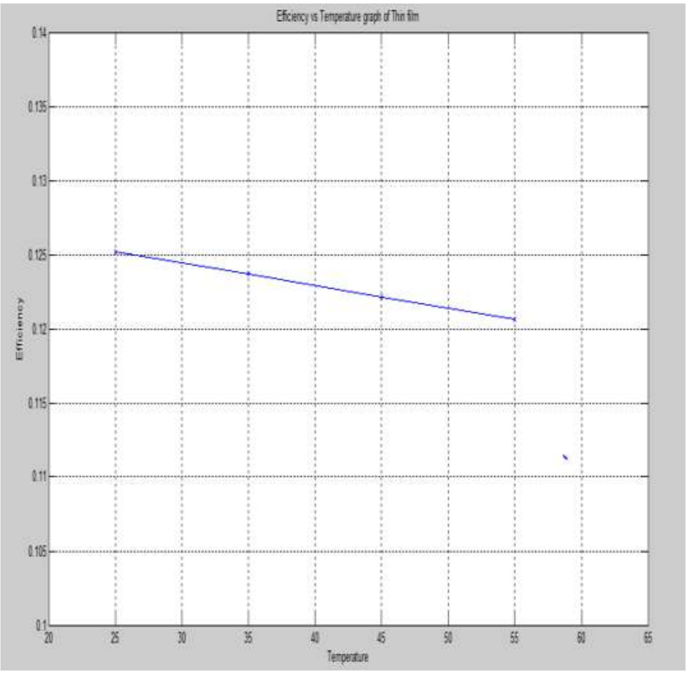


Figure 11: Efficiency with Temperature of Thin film solar cell

The efficiency of thin film solar cell reduced from 12.5% at 25°C to 12% at 55°C. This shows that thin film solar cells are the most temperature tolerant solar cells. The efficiency was reduced with increasing temperature but the rate of reduction was the lowest among other solar cells.

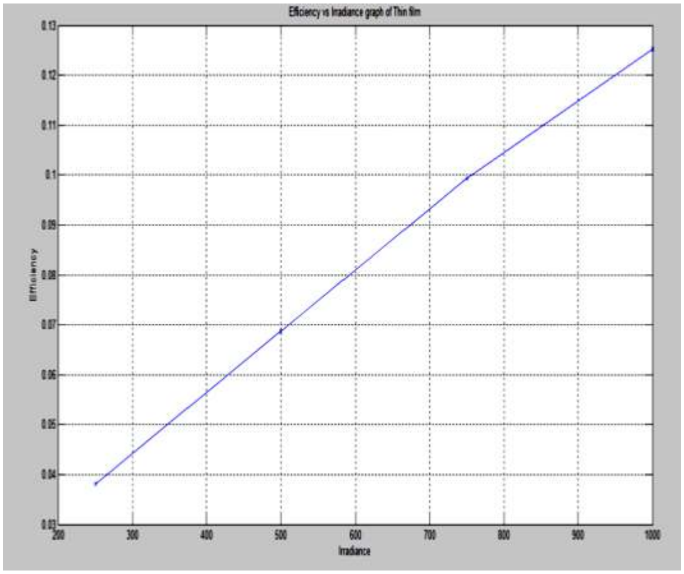


Figure 12: Efficiency with Irradiance Thin film solar cell

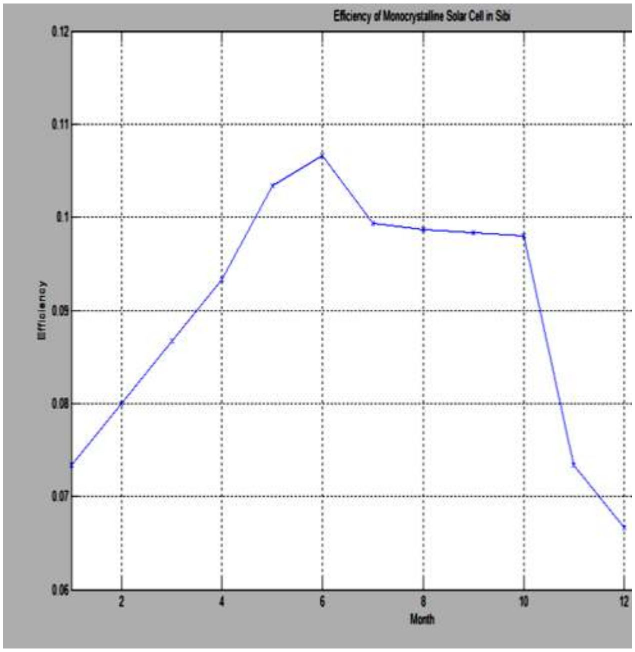


Figure 13: Efficiency of MonoCrystalline in Sibi

The efficiency of the solar cell fell to lowest values when the irradiance was the minimum in Sibi. The highest efficiency of the solar cell came in June when the irradiance was maximum. The efficiency in June fell from 20% to 10.5% in June due to the high temperature of Sibi.

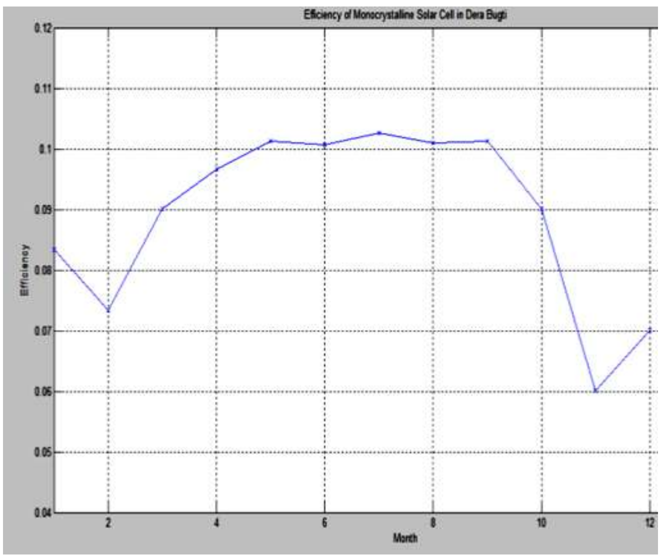


Figure 14: Efficiency of Monocrystalline in Dera Bugti

The Monocrystalline silicon solar cell in Dera Bugti was similar to that in Sibi except for the months where the irradiance in Dera Bugti was more than Sibi. The lowest efficiency was seen in November where the irradiance value was the lowest.

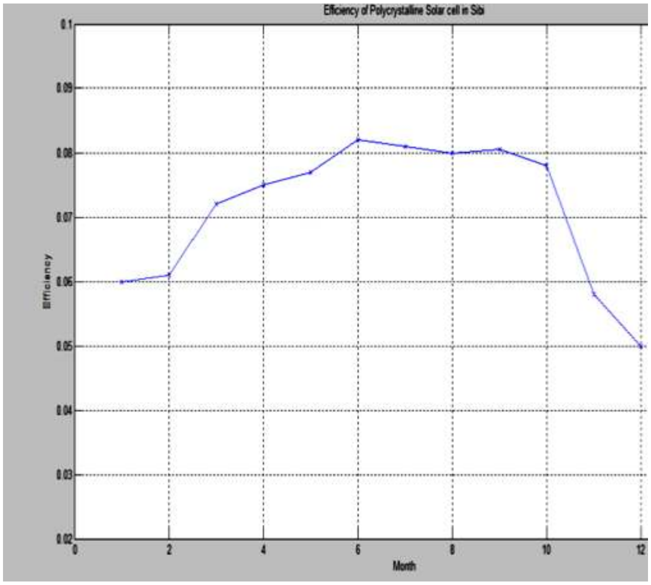


Figure 15: Efficiency of polycrystalline silicon solar cell in sibi

The efficiency of Polycrystalline silicon solar cell in Sibi is less than the monocrystalline silicon. This is because polycrystalline silicon solar cell is less temperature tolerant.

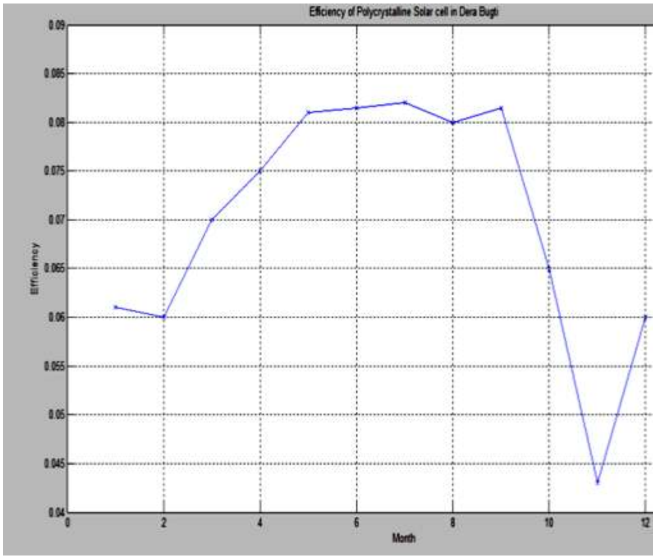


Figure 16: Efficiency of Polycrystalline silicon solar cell in Dera Bugti

The thin film solar cells are tolerant to temperature more than other solar cells and the efficiency reduced but it was tolerant to heat more than other two solar cell types. The lowest efficiency was observed in December in Sibi because of the lowest irradiance.

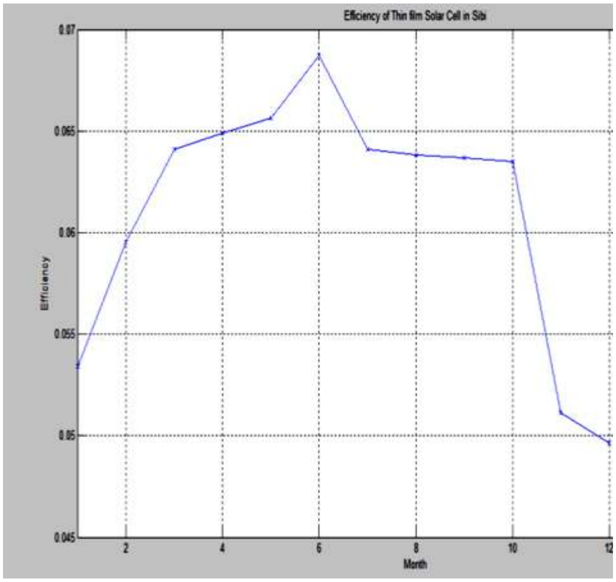


Figure 17: Efficiency of Thin Film in Sibi

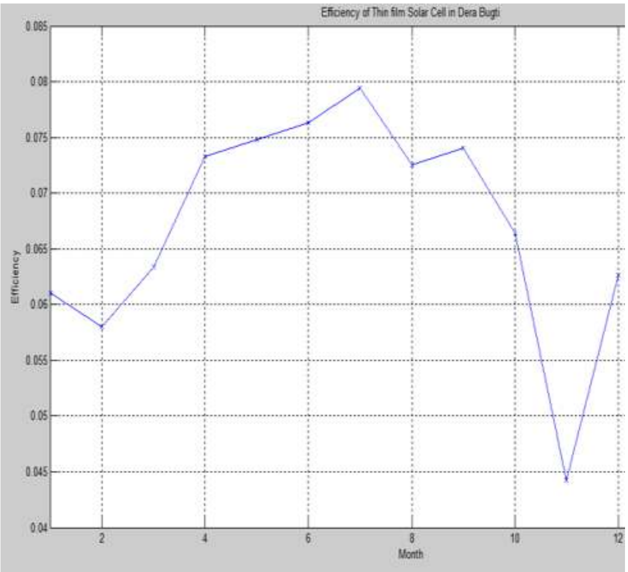


Figure 18: Efficiency of thin film in Dera Bugti

The efficiency of thin film solar cell was more in Dera Bugti than in Sibi because of less hot temperature and more irradiance.

CONCLUSION

Temperature affects the solar cells a lot. It decreases their efficiency by increasing the short circuit current slightly and decreasing the open circuit voltage. When the model of monocrystalline silicon solar cell was simulated with different values of temperature it reduced its efficiency from a maximum of 20% to 16.5% for an increase of 30°C. For a similar approach polycrystalline silicon solar cell showed more decrease in efficiency for a similar temperature difference. Whereas amorphous silicon solar cell showed the least difference in the efficiency.

Based on this research the most temperature tolerant silicon solar cell was amorphous silicon and the least temperature tolerant silicon solar cell was polycrystalline silicon solar cell. This means that in hot regions the amorphous silicon solar cells would not reduce their efficiencies as much as polycrystalline silicon solar cell which has the least temperature tolerance among the three.

The effect of radiating light on the efficiency of different types of solar cells is similar. Increasing the irradiance also increases the efficiency of solar cells. This is because the photovoltaic effect takes place only when light falls on the solar cells. If light does not fall on the solar cell the photovoltaic effect does not take place and hence no electricity is produced. So, the efficiency of the solar cells depends greatly on the irradiance.

In arid and dusty region, the high-speed winds will reduce the efficiency of the solar cells a lot due to reduction in irradiance. But, in humid region the high-speed winds can reduce the temperature (Mehmet, 2011) without affecting the irradiance much. This could improve the efficiency of the solar cell. The cell temperature will reduce as the air speed will rise (Schwingshackl, 2103). Extra heat can be removed from the surface of the photovoltaic cell by raising the speed of wind (Mekhilef, 2012).

According to this research when the models were simulated with the data of Sibi and Dera bugti. They showed different results of efficiency. As the average temperature of Sibi is more than Dera bugti the amorphous silicon being more heat tolerant reduced its efficiency at a lower rate than its crystalline counter parts. The most efficient in these conditions was monocrystalline among the three in these two regions because of the high purity silicon. But this efficiency comes at a very high price as monocrystalline silicon solar cells are expensive.

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