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Experimental Study focused on improving Efficiency of Solar Photovoltaic Array using Conventional Cooling Method.

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Abstract— Renewable Energy System emerges in the present scenario as the most viable solution to the prevailing energy demand supply imbalance. Photovoltaic system presents a practical solution to the energy crisis prevailing in the entire world and is capable of being used effectively by converting the solar radiation into electricity used for powering the various household appliances.

PV Cell converts the part of the solar energy into electricity and rest is dissipated in the form of heat. This heat is inversely proportional to the efficiency of the PV Cell. Thus various techniques are being implemented nowadays in order to keep this efficiency reduction to the lowest minimum possible. The cell operating temperature should be maintained in the specified range so as to achieve reasonable conversion efficiency.

Index Terms— PV- Photovoltaic, FF- Fill Factor.

1 Introduction

THE electrical efficiency of Photovoltaic (PV) cell depends on its temperature during absorption of solar radiation. It is well known that power of PV module usually falls at the rate of (-)0.43 % per degree centigrade with increase in ambient temp above 25 degree centigrade. Hence Temperature control is of utmost importance in order to keep the optimum efficiency of Solar Cells. Since, the efficiency depends on the spectrum and the incident sunlight and the temperature of the solar cell. Conditions under which efficiency is measured must be carefully controlled in order to compare the performance of one device to another. There will be decline in the open circuit voltage and increase in current with rise in temperature.

PV Cell suffers from the high temperatures reached under the high irradiation conditions. Various factors are affected by an increase in the temperature, and are open circuit voltage, short circuit current, curve factor and efficiency. The curve factor and efficiency are both shows reduction with an increase in temperature [0]

2 Various Factors Affecting The Performance Of The Solar Cell

2.1 Maintaining the Operating Temperature within Specific Range

Increase in the operating temperature leads to reduction in the band gap resulting in the reduction in the Open Circuit voltage V and an increase in the short circuit current.

The expression for open circuit voltage and the short circuit current are as follows:

$$V_{OC} = V_O (1 + \alpha\Delta T)$$
$$I_{SC} = I_O (1 + \beta\Delta T)$$

The temperature coefficient is negative for the open circuit voltage and is also usually larger than the temperature coefficient of the short circuit current and thus, the value of power and voltage both reduces while the value of current increases even with the small rise in temperature.

Temperature variation also affect the Fill Factor. The maximum theoretical FF from a solar cell can be determined by differentiating the power from a solar cell with respect to voltage and finding where this is equal to zero. Hence,

$$\frac{d(VI)}{dV} = 0$$

A key limitation in the equations described above is that they represent a maximum possible FF, although in practice the FF will be much lower. Therefore, the FF is most commonly determined from measurement of the IV curve and is defined as the maximum power divided by the product of I_{sc}*V_{oc}, i.e.:

$$FF = \frac{Vmp\ \mathrm{Im}\ p}{Voc.Isc}$$

Where, V_{MP}= Maximum possible Open Circuit Voltage
I_{MP}= Maximum possible Short Circuit Current
V_{0c} = Open Circuit Voltage
I_{SC}= Short Circuit Current

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2.2 Intensity of Solar Radiation

The photocurrent in the PV cell is directly proportional to the solar intensity. There is decrease in the output power with the incident solar energy and this decrease is nearly linear in nature. It means reduction in the intensity of the solar radiation leads to the linear reduction in the output power [1].

2.3 Sun Angle

Output power of PV cell is calculated by taking the cosine function at the sun's angle. This angle should lie in the range of 0^0 to 50^0. On exceeding the sun's angle beyond 85^0, power output is negligible. Thus, this also constitute the important parameters required for the assessment of the PV cell performance [3].

2.4 Wind Speed and its Direction

These affect the temperature uniformity of the PV array. In the condition having low wind speed, there is temperature non-uniformity between modules with top row modules having higher temperature when compared to the bottom row. This is because the heats from the modules flow upwards as these modules are pitched at 23^0 to the horizontal. In case of high wind conditions, the air takes away the heat in such a way that the side of the module which is hit first by the air is having the lowest temperature and the temperature rises at the other side of the array where the air exits [4].

3 Losses in the PV Cell With Rise InTemperature

The heat generated due to the rise in temperature is also conductive to various losses occurring in the PV module thereby leading to the reduction in the efficiency. These occurs due to conduction, convection and radiation.

These modules radiate heat to the environment. Wind flowing across the module leads to the convective heat transfer and the heat transfer from one material to another results in the conductive heat loss. Thus, cooling of the PV module is very much required in order to keep the temperature of the PV module within the specified limit [2].

4 Experiment Conducted

There are 04 Nos. of Arrays (Strings) with 20 Nos. of modules in each and two arrays having 5kW capacity each are connected in series installed in building No. 33, Khas Tatti (plant roots) were hanged from the top of the module in order to provide cooling for the area behind the 02 modules connected to String-1 and rest of the modules connected to String-2 are not provided with this arrangement. Both the modules connected to String-1 shows almost the same reading, so for simplicity only 01 module is selected from String-1, and is named as Panel-1. Similarly, one module out of 02 modules in String-2 is selected, and is named as Panel-2.

Each of these module has 250Wp capacity, V_{OC}= 37.32V, I_{SC}= 8.57A, V_{PM}= 30.34V, I_{PM}= 8.24A. Each module consists of 60 mono crystalline cells with operating temperatures between -20^0C to $+85^0C$ and has the temperature coefficients- Power: -0.43%K, Current: +0.06%K, Voltage: -0.36 %K.

Various parameters like temperature at the front and back of the module, current, voltage and power were measured between 11:00 hrs to 15:00 hours for five days from 27.05.2013 to 31.05.2013. Comparative analysis is done with respect to Panel-1 and Panel-2. Temperature variations are observed at the regular time interval of 01 hour between 11:00 AM to 3:00 PM as the sunlight falling on the earth surface is maximum in this duration. Ambient temperature is in the range of 40-44^{o}C. Laser Gun is been used for the temperature measurement. Water is sprinkled at the regular interval of 30 minutes on the Khas Tatti (plant roots). The wet Khas Tatti acts as the heat exchanger thereby allowing the air passing through it to be cooled.

Fig. 1: Khas Tatti for rendering cooling effect on the PV Panel

The values for Voltage, Current and Power is taken from the Data Logger for these PV Panels. Data as observed during this period are as under:

Date: 30.07.2013

Time (Hrs.)	Without Khas Tatti				
	Without Khas Tatti Panel-2		String-2		
	Temperature at the front of module T(F)2	Temperature at the back of module T(B)2	V Voltage (in Volts)	I Current (in Amps)	W Power (in Watts)
11.00	52.40	55.60	503	5.79	2914
12.00	54.60	58.80	489	6.42	3145
13.00	54.90	58.20	488	6.21	3069
14.00	57.60	60.80	485	6.02	2924
15.00	54.10	59.20	496	5.31	2638

Table- 1

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Table-1 shows the variation occuring in the temperature

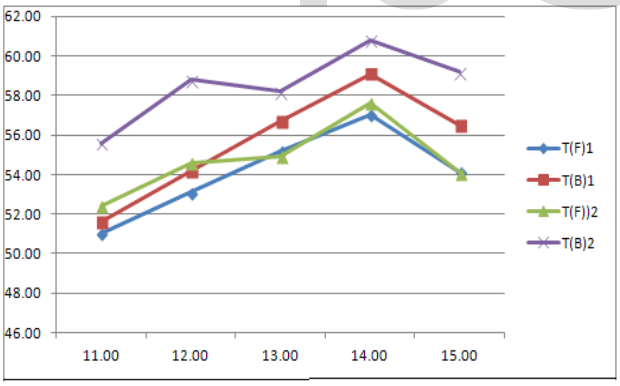
throughout the day, thereby leading to the power generation variations through the Photovoltaic (PV) cell installed at the terrace of the building. The above data is obtained without the application of any cooling technique.

Time (Hrs.)	With Khas Tatti				
	Khas Tatti Panel -1		String-1		
			V	I	W
	Temperature at the front of module T(F)1	Temperature at the back of module T(B)1	Voltage (in Volts)	Current (in Amps)	Power (in Watts)
11.00	51.00	51.60	500	5.90	2949
12.00	53.10	54.20	500	6.45	3228
13.00	55.20	56.70	492	6.38	3108
14.00	57.00	59.10	489	6.31	3083
15.00	54.10	56.50	491	5.78	2842

Table-2

Table-2 shows the data taken from the same site location but after the application of the Cooling technique i.e. by using the Khas Tatti.

The comparison is shown through the graphical representation below:



Graph of Temperature (Degree Centigrade) Vs time of the day (11 am to 15 pm) on 30.05.2013 (Thursday)

Time	Comparison		
	W1	W2	S=W1-W2
	Power (Khas Tatti) in Watts	Power (Without Khas Tatti) in Watts	Saving (in Watts)
11.00	2949	2914	
12.00	3228	3145	
13.00	3108	3069	39
14.00	3083	2924	159
15.00	2842	2638	204

Table-3

Table-3 shows the Saving in Watts by providing the required cooling effect of khas tatti which is effective between 13-15pm.

The efficiency of a solar cell is determined as the fraction of incident power which is converted to electricity and is defined as:

$$P_{max} = V_{OC} I_{SC} FF$$

$$\eta = \frac{V_{OC} I_{SC} FF}{P_{in}}$$

Where, V_{0C} = Open Circuit Voltage
I_{SC} = Short Circuit Current
FF = Fill Factor
P_{max} = Maximum Power through Solar Cell
P_{in} = Input Power required by the Solar Cell
η = Efficiency of the Solar Cell

The "fill factor", more commonly known by its abbreviation "FF", is a parameter which, in conjunction with V_{oc} and I_{sc}, determines the maximum power from a solar cell.

Under the Standard test conditions, PV modules that are commercially available converts only 4-18% of the solar radiation to electricity, depending upon cell type and operating conditions. This efficiency reduces by 0.2-0.5% per degree Centigrade rise in ambient temperature. Standard test condition refers to as spectral distribution of AM1.5; solar irradiation, G=1000 W/m^2 , cell temperature= 25^0C and wind speed < 1 m/sec [5].

Thus, in order to increase the efficiency of the Solar Photovoltaic Module, temperature control is of prime importance in comparison to the various other factors.

Conclusion

It is observed from the above data that the temperature difference between Panel-1 and Panel-2 is approximately 1-6 degree Centigrade , but it is also noted that the temperature difference between front and back of the module is very less in comparison i.e. the modules covered on the back by khas tatti results in the cooling effect generated there and thus, the power generation is increased upto 200W in between 13-15pm approximately as seen from the above data.

Following observations are made considering the incoming radiation as constant. Since, these radiation varies throughout the day, but the observations for each of the string is made at the same instant and thus it is assumed constant.

Continuous sprinkling of water on khas tatti is expected to give improved result. Hence, this technique may be suitably adopted in the afternoon between 13-16 pm. There is great potential in using solar energy in India for satisfying our ever increasing electricity requirement.

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