Deviation in the performance of Solar Module under Climatic parameter as Ambient Temperature and Wind Velocity in Composite Climate

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Abstract- An effort has been made to develop an equation with the given data for different seasons of particular location called Lucknow, India consisting of composite climate, which is helpful in developing a relation of efficiency of photovoltaic modules with the major climatic parameters like temperature, wind velocity; further this equation developed mathematically is in good correlation with the measured data. Here data are shown for a whole year from 2010-2011 considering daily monthly average values of the variables (efficiency with temperature and wind velocity). Here performance of module gives a broad view of impact of climatic variables and helps us to find out the efficiency of modules while knowing the climatic parameters of a particular area.

Keywords- Ambient (atmospheric) temperature, wind velocity, regression analysis, efficiency of solar photovoltaic module.

1. Introduction

The basic characteristics which govern PV module electrical characteristics are mainly maximum power, tolerance rated value %, maximum power voltage, maximum power current, open-circuit voltage (Voc), short-circuit current (Isc), maximum system voltage.

Determining the performance of a PV system not only depends on its basic characteristics but in the environment that they are placed, this system will measure the effect of high ambient temperature, humidity, wind velocity, on its working effectiveness as ‘‘as discussed by Omubo-Pepple et al [1]”.

The operating temperature plays a central role in the photovoltaic conversion process. Both the electrical efficiency and the power output of a PV module depend linearly on the operating temperature, the various correlation proposed in the literature represent simplified working equations which can be applied to PV modules or PV arrays mounted on free standing frames PV, thermal collectors and PV arrays respectively ‘‘as discussed elsewhere [1,2]”.

The quantities labelled NOCT are measured under open circuit conditions while operating in the so called nominal terrestrial environment (NTE) defined as

Global solar flux --- 800 W/m^2, which is one of the important parameters affecting the performance of photovoltaic module. Researches have been done including Characteristics Distribution of Total, Diffuse and Direct Solar radiation, relation of radiation with ambient temperature and also Instant Solar Radiation and Its Dependence on Metrological parameter’ as discussed elsewhere [3-5]”.

Air temperature	293.16 K (20^{o}c)
Average wind speed	1m/s

Different studies have been performed by the researchers on qualification testing of photovoltaic modules, energy analysis of panels, maximum power point control of Photovoltaic System ‘‘as discussed elsewhere [6-8]”. Different climates have been studied using different types of modules [9]

Previous researches also include laboratory testing of module, manufacturing, reliability and performance testing ‘‘as discussed elsewhere [10-12]”. Tests have been performed to get Effective Efficiency of PV modules under Field Conditions, also corrosion effects in modules, performance evaluation for climatic application ‘‘as discussed elsewhere [13-16]”

New Methodologies have been used to Optimize Solar Energy Extraction under Cloudy Conditions ‘‘as discussed by S. Armstrong et al [17]”.

Comparison of Degradation rates of individual modules held at maximum power have been done[18], not only this but Silicon photovoltaic modules a brief history of the first 50 years has been studied‘‘as discussed by Green M. A [19]” Long term performance studies of modules and their reliability have been carried out in previous years including equations and applications associated with the photovoltaic array performance[21].

But the functioning of solar devices at any time depends on the ambient variables like radiation, temperature, humidity, dust, wind velocity, cloud cover, clearness index, etc. Sometimes when we want to get the value of instant efficiency of module to test the functioning of module at that instant , the instrument measuring it are not found. The main aim of this paper is to solve this kind of problems. Here an attempt has been made to obtain a relation among efficiency, temperature and wind velocity, so that instant efficiency of the module can be estimated by measuring temperature, wind velocity using simple devices.

The correlations expressing the PV module performance as a function of weather variables such as the ambient temperature, local wind speed, etc. have been discussed in this section and therefore finding the deviation in the performance of solar module under climatic parameter as ambient temperature and wind velocity for a given location.

2. Instrumentation

SPV Module No 2007.20.685 manufactured in the year 2007 by M/s Rajasthan Electronics and Instruments Ltd, Jaipur, India has been studied. The module has been connected to the rheostat, ammeter, digital multimeter (DT9205A). The other instruments used are digital thermometer (SE-221-P-K) to measure cell temperature, thermo-hygro clock (288-CTH, Agronic Ltd.) to measure ambient temperature and humidity and digital luxmeter (range-0 to 50,000 Lux in three ranges of 0to 2000, 0 to 20,000 and 0 to 50,000 lux, accuracy +-5% , +-2 least count) to measure solar flux, anemometer to measure wind velocity.

The commercial photovoltaic module used has the following components

Solar Type: Poly- crystalline silicon
Cell Area: $0.216\ m^2$
Electrical Efficiency STP: 12% with a power peak of 36 watt.
Electrical Specifications: At standard test conditions of 100mw/sq cm.AM (air mass) 1.5 and at25^{o}C cell temperature within normal production of tolerance +-3%.
Area of the panel: $0.340\ m^2$

3. Methodology

General variation in efficiency with respect to temperature and wind velocity has been recorded which has been observed to be same for all the days, here readings have been taken for a whole year 2010-2011,considering daily monthly average values of all variables (efficiency, temperature and wind velocity respectively) neglecting humidity, cloud cover, dust, clearness index etc.

Here the data given by the manufacturer including the efficiency of solar photovoltaic module in Lucknow, India is verified by establishing a correlation between the efficiency of solar photovoltaic module and ambient temperature and wind velocity.

The efficiency of solar photovoltaic module obtained during the day has different values. This fluctuation results from different factors affecting the performance of solar photovoltaic module. For example, these factors may be humidity, cloud cover, dust, etc.

The aim of this study here is to find out the variation of efficiency of solar photovoltaic modules with ambient temperature and wind velocity collectively. So, the dependence of efficiency of solar photovoltaic module on different factors except ambient temperature and wind velocity are neglected.

To develop the relation of efficiency of solar photovoltaic module with ambient temperature and wind velocity, data for efficiency of solar photovoltaic module and ambient temperature, wind velocity are needed. So the efficiency of solar cell and corresponding temp and wind velocity are taken into account.

Efficiency of solar module has been found with the help of maximum power, solar flux, and the area of solar panel, on the other hand ambient temperature and wind velocity has been recorded with the help of thermo-hygro clock and anemometer respectively.

Table 1. Efficiency of Solar Module, Ambient Temperature, Wind Velocity Data for a year (2010-2011)

Month	Daily Monthly Average values of efficiency (η) (%)	Daily Monthly Average values of temperature(T)(^{o}C)	Daily Monthly Average values of wind velocity(V) (m/s)
January	13.2695	21.24	1.10
February	11.8916	24.72	1.53
March	12.1849	29.58	1.25
April	11.3681	36.21	1.73
May	10.8800	40.84	0.96
June	10.8265	41.36	1.11
July	12.0602	37.47	1.14
August	12.8101	38.36	1.75
September	Data unavailable due to rainy month		
October	12.6397	33.15	1.29
November	12.8814	26.80	0.51
December	13.2708	22.44	0.82

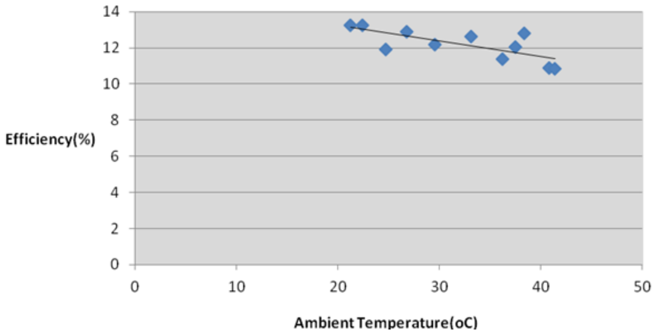

Fig. 1. Relation between daily monthly average values of efficiency and temperature for a whole year (2010-2011

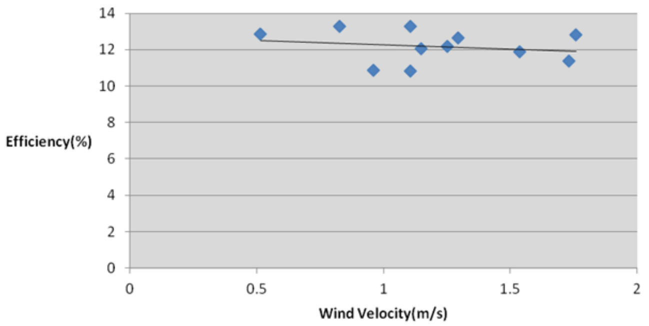

Fig. 2. Relation between daily monthly average values of efficiency and wind velocity for a whole year (2010-2011).

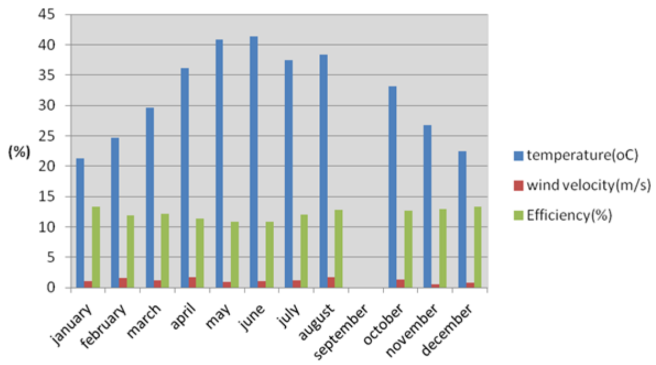

Fig. 3. Variation of daily monthly average values of efficiency with different climatic parameters (daily monthly average values of temperature, and wind velocity) for a whole year (2010-2011

4. Calculation

For calculations of the relation, we have used the process of linear regression as it is given by the method of least square solved for three variables. Problems involving more than two variables can be treated in a manner analogous to that for two variables, for example there may be a relationship among three variables T, V, η that can be described by the equation

$$\eta = a_o + a_1 T + a_2 V \quad (1)$$

Which is called a linear equation in the variables T, V, η, and the actual sample points (T_1, V_1, η_1), (T_2, V_2, η_2) may scatter not too far from this plane which we call an approximating plane.

Table 2. Method of least square for three variables

0	T	V	T^2	V^2	T V	T η	V η
13.2695	21.25	1.10	451.56	1.23	23.53	281.98	14.69
11.8916	24.72	1.53	611.08	2.36	38.01	293.96	18.28
12.1849	29.58	1.25	874.98	1.56	37.01	360.43	15.25
11.3681	36.22	1.73	1311.89	2.99	62.73	411.75	19.69
10.8800	40.84	0.96	1667.91	0.92	39.25	444.34	10.46
10.8265	41.37	1.10	1711.48	1.23	45.81	447.89	11.99
12.0602	37.47	1.14	1404	1.32	43.04	451.89	13.85
12.8101	38.36	1.75	1471.49	3.09	67.49	491.39	22.54
12.6397	33.15	1.29	1098.92	1.67	42.91	419.01	16.36
12.8814	26.80	0.51	718.24	0.26	13.80	345.22	6.63
13.2708	22.44	0.82	503.55	0.68	18.53	297.79	10.96
∑ η =134.08	∑ T =352.2 0	∑V =13 .24	∑ T^2 =11825. 1	∑V^2 =17 .31	∑TV =432 .11	∑ Tη =4245 .66	∑V η =160 .70

N=11

$\sum \eta = a_o N + a_1 \sum T + a_2 \sum V$

$\sum T\eta = a_o \sum T + a_1 \sum T^2 + a_2 \sum TV$

$\sum V\eta = a_o \sum V + a_1 \sum TV + a_2 \sum V^2$

$134.0828 = 11a_o + a_1(352.2) + a_2(13.2399)$ (1)

$4245.66 = a_o(352.2) + a_1(11825.1) + a_2(432.11)$ (2)

$160.7 = a_o(13.2399) + a_1(432.11) + a_2(17.311)$ (3)

$12.1893 = a_o + a_1(32.0182) + a_2(1.2036)$ (4)

$12.0547 = a_o + a_1(33.5749) + a_2(1.2268)$ (5)

$12.1375 = a_o + a_1(32.6369) + a_2(1.3075)$ (6)

while solving equation (4) and (5) we get

$0.1346 = -1.5567 a_1 - 0.0232 a_2$ (7)

while solving equation (5) and (6) we get

$0.0518 = -0.6187 a_1 - 0.1039 a_2$ (8)

while simplifying equation (7) and equation (8) we get

$0.0864 = -a_1 - 0.0149 a_2$ (9)

$0.0837 = -a_1 - 0.1679 a_2$ (10)

and solving the above equations we get

$0.0027 = -0.153 a_2$

$a_2 = 0.017647$

keeping the value of a_2 in equation (9) we get a_1 as

$a_1 = -0.08666$

keeping the value of a_1 and a_2 in equation (4) we get

$a_o = 14.9852$

therefore, the equation comes out to be as compared with equation (A).

$$\boldsymbol{\eta = 14.9852 - 0.08666\,T + 0.017647\,V}$$

where V, T, η are three variables, T and V are considered to be independent variables and η to be considered as dependent variable (V = wind velocity and T = temperature and η = efficiency of solar photovoltaic module).

In statistics multiple linear regression is an approach to modeling the relationship among the three variables and therefore estimating the value of unknown variable (η = efficiency) with the help of known one (V = wind velocity), (T = ambient temperature) has been carried out.

5. Discussion

We have made an effort to test the validity of the equation found out. Table 3 gives value of η measured and calculated.

Table 3. Values of η measured and calculated

Months	η measured (from measured values)	Hcalculated (calculated from equation)	Difference of the two η values	Percentage (%) error
January	13.2695	13.1633	0.1062	0.8003
February	11.8916	12.8671	-0.9755	-8.2032
March	12.1849	12.4436	-0.2587	-2.1231
April	11.3681	11.8765	-0.5084	-4.4721
May	10.8800	11.4627	-0.5827	-5.3556
June	10.8265	11.4197	-0.5932	-5.4791
July	12.0602	11.7582	0.3020	2.5041
August	12.8101	11.6916	1.1185	4.7313
September	Data unavailable due to rainy month			
October	12.6397	12.1352	0.5045	3.9913
November	12.8814	12.6718	0.2096	1.6271
December	13.2708	13.0548	0.2160	1.6276
	∑ η Measured (η_1) =134.0828	∑ η Calculated (η_2) =134.5440		

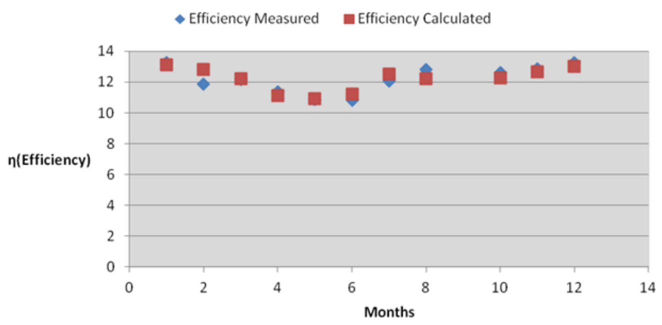

Fig. 4. Value of η (Efficiency of solar photovoltaic module) calculated from equation and obtained from measured data (for one year 2010-2011)

Calculation of Multiple Correlation Coefficient = R = ∑ η 1∑ η 2/√ (∑η 1)2(∑η 2)2 = 1

Where η 1 = Measured value of efficiency of module obtained experimentally,

Where η 2 = Calculated value of efficiency of module obtained from the equation.

R = (134.0828) (134.5440)/√ (134.0828)2(134.5440)2 = 18040.0362/√ (17978.1972) (18102.0879) = 18040.0362/18040.0362 = 1

According to the properties of multiple correlation coefficient, if the value of R (multiple correlation coefficient) comes out to be unity (1), then the observed and expected value obtained for the efficiency of module (η) coincide and the observed (η) is a linear function of V and T.

It measures the closeness of the association between the observed values and the expected values of a variable obtained from the multiple linear regression of that variable on other variables. So far we have seen correlation between two variables only; often it is necessary to find the correlation among three or more variables.

So whenever we are interested in the combined influence of a group of variables, upon a variable, our study is that of multiple regression and multiple correlation.While keeping manual error in mind the values obtained (η measured and η calculated) are quite in agreement with each other and as seen from the table the percentage error is considerably small, the equation obtained may be taken as valid equation.

So using the equation I, efficiency of solar photovoltaic module (η) can be calculated by using the known values of ambient temperature (T) and wind velocity (V).

For subsequent development of such type of relation, the effects of dust, cloud cover, humidity, and clearness index may also be taken into account in developing the relationship.

Efforts are being made to evolve such equations which not only include temperature, wind velocity but temperature, humidity, wind velocity, dust etc so as to get a deep study over the relationship of all major climatic parameters with the efficiency of solar photovoltaic modules.

6. Conclusion

Many studies have shown that silicon solar photovoltaic module operating efficiency is at optimum level in moderately low air temperatures. While considering the second parameter wind velocity, the local winds include relatively extensive monsoon in India. Other local winds are the cyclone type, although the silicon solar photovoltaic module output is not usually affected by moderate wind directly but it has relevance to other climatic parameters like temperature, humidity, dust and dirt on solar photovoltaic modules in composite climatic conditions, the proposed study aims to go in depth on combine consideration of two climatic parameters (temperature and wind velocity) on the performance of the solar photovoltaic modules.

An attempt has been made to develop equations to calculate efficiency of solar photovoltaic modules from ambient temperature and wind velocity data for a whole year, the developed equations show very good correlation with measured results for almost every day for whole year, this is clear from calculated percentage error. Till date the preliminary investigation done include either effect of temperature on efficiency of module or on power output obtained with the increase or decrease in temperature or under operating or standard reporting conditions how to characterize the electrical performance of photovoltaic modules, the study done under this paper would help us to characterize the photovoltaic modules used with the combined consideration of either two ambient variables or three or all major ones while helping us to propose the efficiency of modules even if it is unknown to us by the manufacturer.

It is considered that manufacturers is supposed to provide the information regarding the module which may include the variation of the efficiency with temperature, wind velocity but not necessarily all the information may reach to the user . The specification given by the manufacturer of different types of silicon solar PV modules are usually for standard test conditions (STC), obtained under simulated sunlight conditions. As a result the module performance varies with the location of use and actual environmental conditions, which they are subjected to. This is because of variation of air mass, and other meteorological parameters of the local environment such as irradiation (solar flux), temperature, relative humidity and wind speed [22].

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