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Statistical Analysis of the Performance of Solar Photovoltaic Module with the Influence of Different Meteorological Parameters in Tripura, India.

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Abstract - An equation has been developed to measure the efficiency of PV module instantly, if the climatic parameters of the area are known. The measured and calculated values of efficiency are verified to check the percentage error between them. It is observed that developed equation has very correlation with the measured values.

Keywords - PV module efficiency, ambient temperature, wind speed, solar radiation, relative humidity, correlation.

I. Introduction

PVarray has its own importance in electrical applications. At the same time, the use of energy should be economical, environmentally friendly and socially acceptable. The current trends in energy consumption are neither secure nor sustainable. The rising consumption of fossil fuels, together with increasing greenhouse gas emission, threatens our secure energy supply. Therefore development of clean, secure, sustainable and affordable energy sources become very much essential. One of the promising applications of solar energy technology is photovoltaic systems to generate electric power without emitting pollutants. Increasing efforts are directed towards reducing the installation costsand enhancing the performance of photovoltaic systems so that the system can be deployed at a large scale.

The efficiency of the module has dependency on the environmental parameters of different area of research [1-2]. Meteorological data such as solar radiation, ambient temperature, relative humidity, wind speed are accepted as dependable and widely variable renewable energy sources [3]. A number of researchers have investigated how an increase in the temperature influences the electrical properties of PV devices in a controlled environment [4-7]. This paper presents a mathematical model to predict module efficiency based on the ambient temperature, wind speed, wind direction, relative humidity. Long term performance studies of modules and their reliability have been carried out in previous years including equation associated with the PV array performance [8].Sometimes it become necessary to verify the data given by the manufacturer as the functioning of the solar module depends on different climatic variables including temperature, humidity, wind velocity, clearness index, wind direction etc. [9]. In order to test the performance of PV array as specified by the manufacturer it is important to investigate the effect of ambient parameters on the PV module output [10-11]. Sometimes it is also necessary to find the instant efficiency to test the functioning of the module at that instant. Here an attempt has been made to obtain an equation among efficiency, temperature, humidity, wind speed and radiation which helps to find out the instant efficiency at any instant. A statistical analysis has been done for the independent and dependent variables for a particular location. The investigation is carried out by monitoring the variation of power output of the system with ambient temperature.

II. Materials and Methodology

The experiment has been done with Solar Photovoltaic Module No: 03018119, manufactured by M/S TATA BP SOLAR INDIA LTD, INDIA, as shown in Fig.1. A digital multimeter (M3900) is used to measure the short circuit current and open circuit voltage. One digital thermometer (MS2101) has been used to check the ambient temperature, and TENMARS TM - 207 solar power meter to measure the intensity of the solar radiation.

Solar type: Mono-crystalline
Maximum power: 37 W
Cell area: 0.3239 sq. meters.
Open circuit voltage: 21 V
Short circuit current: 2.50 Amp
Voltage at maximum power: 16.4 V
Current at maximum power: 2.26 Amp

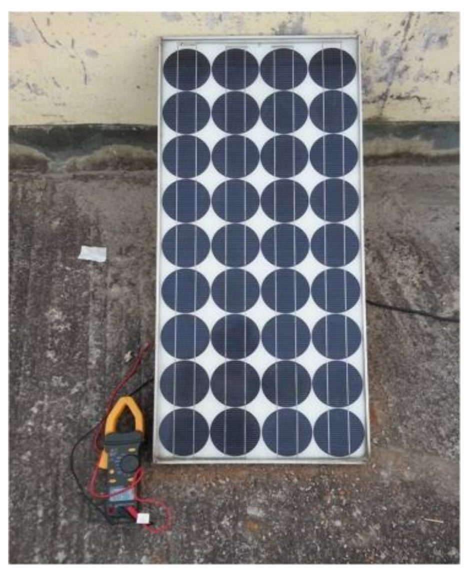

Fig. 1.Solar photovoltaic module.

The variation of efficiency with respect to ambient temperature, relative humidity, wind speed, solar radiation has been taken for the month of June, September and December 2011. The average of maximum and minimum values of all the variables has been taken. For each month ten numbers of data have been taken for each variable.

Now, the data for different climatic parameters like relative humidity, ambient temperature, wind speed, were collected from Agricultural Research Centre, Tripura, India which are shown in Table 1.

Table 1. Input data records of PV module for daily average values of ambient temperature, humidity, wind speed, radiation, voltage, power and efficiency.

Temperature (T)(°C)	Humidity (H)(%)	Wind speed (V)(m/sec)	Radiation (R) (w/m^2)	Voltage (volt)	Power (watt)	Daily efficiency (η) %)
26.66	77	1.11	123	18.8	32.54	10.0463
27.36	71	1.18	149	19.06	34.57	10.6730
26.47	79	0.59	157	18.7	35.9	11.0836
27.35	79	0.79	133	18.79	32.95	10.1728
26.59	73	0.41	105	18.5	38.29	11.8215
26.59	64	0.35	168	17.8	31.44	9.7066
26.55	63	0.84	170	18.6	30.12	9.2991
29.38	60	1.13	96	18.23	34.12	10.5341
28.33	66	0.83	160	19.1	32.13	9.9197
28.015	73	0.20	94	19.4	29.45	9.0923
27.61	77	0.53	142	18.3	28.88	8.9163
26.49	64	0.24	165	18.5	29.99	9.2590
28.44	70	0.55	152	18.55	30.11	9.2960
28.84	70	1.00	128	18.45	30.14	9.3053
27.60	74	0.66	159	17.93	31.11	9.6048
28.96	72	0.69	165	19.21	29.88	9.2250
29.32	72	0.59	158	19.04	28.66	8.8484
29.56	77	0.85	157	18.81	30.59	9.4442
29.8	65	0.56	149	18.78	33	10.1883
26.95	76	1.19	149	18.36	33.55	10.3581
28.55	78	1.37	151	19.06	34.44	10.6329
28.31	60	0.48	168	19.22	35	10.8058
29.32	71	0.15	112	19.1	35	10.8058
27.77	68	1.18	168	18.35	36	11.1145
27.02	70	0.53	145	18.81	37.45	11.5622
27.47	82	0.25	127	18.79	32	9.8795
25.94	77	0.82	150	18.82	29.19	9.0120
25.34	91	0.64	73	17.96	31.66	9.7746
27.35	80	0.47	182	19	33.33	10.2902
28.44	77	0.37	168	19.24	34.4	10.6205

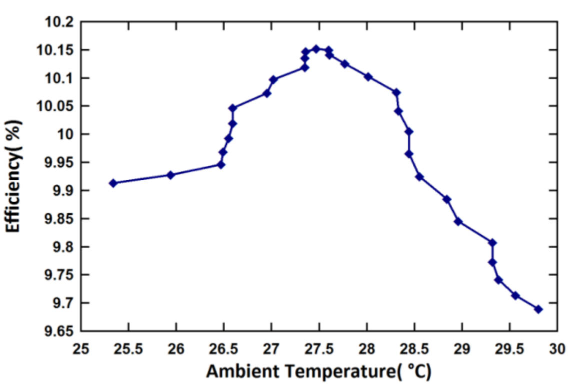

Fig. 3. Variation of PV module efficiency with the variation of daily average ambient temperature.

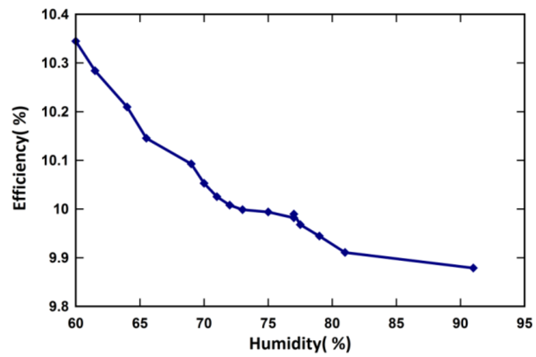

Fig. 4. Variation of PV module efficiency with the variation of daily average humidity.

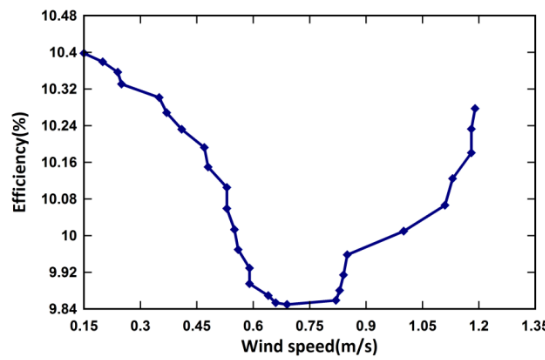

Fig. 5. Variation of PV module efficiency with the variation of daily average wind speed.

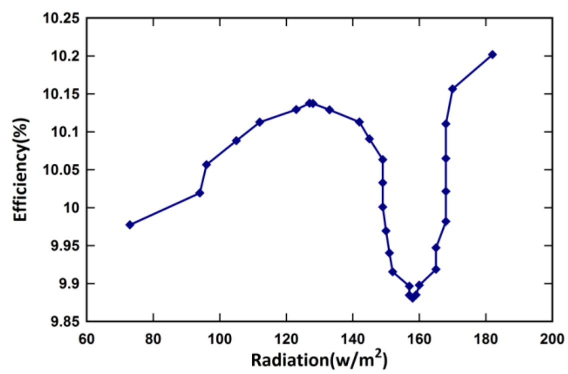

Fig. 6. Variation of PV module efficiency with the variation of daily average solar radiation.

In the present study efficiency has been taken as dependent variable and humidity, temperature, wind speed and solar radiation are taken as independent variables. In the recent study a correlation has been established among the dependent variable (efficiency)and independent variables (humidity, solar radiation, ambient temperature and wind speed) to verify the efficiency given by the manufacturer.

The dependency of efficiency of solar module on different factors except ambient temperature, humidity, wind speed and solar radiation are neglected.

For calculation of the relation, the process of linear regression for four variables has been used. Linear regression models are often fitted using the least squares approach to describe the linear association between quantitative variables, a statistical

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procedure called regression. There may be a relationship among five variables called efficiency, ambient temperature, relative humidity, wind speed and solar radiation, which can be described by the equation.

$$\eta = a_0 + a_{01} T + a_2 H + a_3 V + a_4 R \quad (1)$$

Where a_0, a_1, a_2, a_3 and a_4 are the constants.

The above equation is called a linear equation of the variables η, T, H,V & R and the actual sample points (η_1,T_1,H_1,V_1,R_1), (η_2,T_2,H_2,V_1,R_2),(η_3,T_3,H_3,V_3,R_3) may scatter not too far from this plane which is known as an approximating plane. Regression is used to assess the contribution of one or more "explanatory" variables (called independent variables) to one "response" (or dependent) variable. It can also be used to predict the value of one variable based on the values of others. Here three months has been taken into account and for each month as ten numbers of data has been taken, therefore total number of case (N) is 30. The following equations describes the relationship between the dependent and the independent variables.

$$\sum \eta = a_0 N + a_1 \sum T + a_2 \sum H + a_3 \sum V + a_4 \sum R \quad (2)$$

$$\sum \eta \boldsymbol{T} = a_0 \sum T + a_1 \sum T^2 + a_2 \sum TH + a_3 \sum TV + a_4 \sum TR \quad (3)$$

$$\sum \eta \boldsymbol{H} = a_0 \sum H + a_1 \sum TH + a_2 \sum H^2 + a_3 \sum HV + a_4 \sum HR \quad (4)$$

$$\sum \eta \boldsymbol{V} = a_0 \sum \boldsymbol{V} + a_1 \sum TV + a_2 \sum VH + a_3 \sum V^2 + a_4 \sum VR \quad (5)$$

$$\sum \eta \boldsymbol{R} = a_0 \sum \boldsymbol{R} + a_1 \sum TR + a_2 \sum HR + a_3 \sum VR + a_4 \sum R^2 \quad (6)$$

Putting the values of the variables from Table 2for solving the above equations we get,

a_0 = 3.69, a_1= 0.51186, a_2=-0.0954, a_3=0.000568, a_4= - 0.0069

Therefore a comparative equation may be developed as compared with equation (1) we get,

$$\eta = 3.69 + 0.51186T - 0.0954H + 0.00568V - 0.0069R \quad (7)$$

In the above equation, efficiency (η), Temperature (T), Humidity (H), Wind velocity (V), Solar radiation (R) are five variables in which T, H, V, R are considered as independent variables and η as dependent variable.

III. Results and Discussion

Percentage least square focuses on reducing percentage errors, which is useful in the field of forecasting or time series analysis. Table 2 shows the efficiency (η) of solar photovoltaic module calculated from the above equation and obtained from the measured data to get the error between these two. Now, an effort has been made to test the validity of the equation found earlier. The percentage difference and percentage error between measured and calculated values of efficiencies have been shown in Table 2.

Table 2. Measured and calculated values of efficiencies and measurement of percentage error.

Measured efficiency(η_1) (%)	Calculated efficiency(η_2) (%)	Difference (%)	Percentage error (%)
10.0463	9.1479	0.8984	809425
10.6730	9.8996	0.7734	7.2463
11.0836	8.6223	2.4613	22.2066
10.1728	9.2395	0.9333	9.1744
11.8215	9.6139	2.2076	18.6744
9.7066	10.0375	-0.3309	3.4090
9.2991	10.10145	-0.80235	-8.6282
10.5341	12.3484	-1.8143	-17.2231
9.9197	10.7953	-0.8756	-8.8268
9.0923	10.4180	-1.3257	-14.5804
8.9163	9.4998	-0.5835	-6.5441
9.2590	10.0064	-0.7474	-8.0721
9.2960	10.5236	-1.2276	-13.2056
9.3053	10.8965	-1.5912	-17.0999
9.6048	9.6643	-0.0595	-0.6194
9.2250	10.5100	-1.285	-13.9295
8.8484	10.7420	-1.8936	-21.4004
9.4442	10.3969	-0.9527	-10.0876
10.1883	11.7175	-1.5292	-15.0093
10.3581	9.2128	1.1453	11.0570
10.6329	9.8282	0.8047	7.5680
10.8058	11.3002	-0.4944	-4.5753
10.8058	11.1523	-0.3465	-3.2066
11.1145	10.2646	0.8499	7.6467
11.5622	9.8449	1.7173	14.8527
9.8795	9.0531	0.8264	8.3647
9.0120	8.5915	0.4205	4.6660
9.7746	7.4790	2.2956	23.4853
10.2902 10.6205	8.8082 9.7444	1.482 0.8761	14.4020 8.2491
∑efficiency measured (η_1) =301.2924	∑efficiency calculated(η_2) =299.4600		

Now, to check the closeness of the association between the observed values and the expected values of a variable, the measurement of multiple correlation co-efficient (**r**) becomes necessary.Multiple correlation co-efficient can be determined from the equation given below

$$r = \frac{\sum \eta_1 \sum \eta_2}{(\sum \eta_1)^2 (\sum \eta_1)^2} = 1 \quad (8)$$

Where η_1 = measured value of efficiency of module.

η_2 = efficiency of module calculated from the developed equation.

Using Table 3, from the above equation the value of multiple correlation coefficient comes to 1.

Multiple correlation co-efficient measures the closeness of the association between the measured and calculated values of efficiencies. Fig. 2 shows the closeness of the measured and calculated values of efficiency.

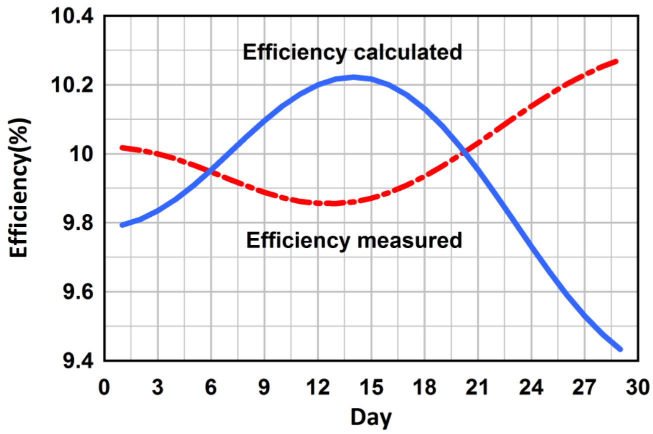

Fig. 2. Variation of measured and calculated values of efficiency of solar photovoltaic module.

The value of multiple correlation coefficient can vary from -1 (perfect negative correlation) through 0 (no correlation) to +1 (perfect positive correlation). According to the properties of multiple correlations co-efficient, if the value of **r** becomes unity, then, the measured value and calculated values of efficiency of the module coincide and the measured value of efficiency (η) is a linear function of temperature (T), humidity (H), wind speed (V) and solar radiation (R).It is seen from the above that, the difference between measured and calculated value of efficiency (η) is considerably small, thus the equation obtained may be taken as valid equation. That, using equation (9), the efficiency of solar module can be found out by the known value of independent variables T, H, V and R of any particular area.

IV. Conclusions:

In the present work, the performance of the solar photovoltaic module have been studied by considering all major meteorological parameters like ambient temperature, humidity, wind speed and solar radiation.

The value of correlation coefficient shows very good correlation with dependent and independent variables. If the other climatic condition such as environmental dust, shading, bypass diode, then also a standard equation may develop to correlate the measured and calculated values of efficiency. It is also concluded that, the module performance varies with the actual environmental condition even though the specifications given by the manufacturer of solar modules are usually for STC. Then, the developed standard equation may be used to propose the efficiency of modules if the different meteorological parameters of the particular area are known.

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