Verification of Quality Parameters of a Solar Panel and Modification in Formulae of its Series Resistance

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***Abstract*—We propose a new formula to calculate the value of Series Resistance from the values of V_{OC}, I_{SC}, V_{MPP} and I_{MPP}. This formula was tested on different solar data in different conditions. The data included the values of V_{OC}, I_{SC}, V_{MPP}, I_{MPP}, Temperature, Irradiance and P_{MAX} at different times during the day for 7 days. From the given data, two values of G and T are considered. Using the above atmospheric conditions and the panel behavior at those conditions, a new formula for calculation of series resistance of the solar panel is proposed**.

Keywords—Series; resistance; Maximum power; formula; solar irradiance; temperature

I. INTRODUCTION

We plan to extract the quality parameters of a Solar Panel at a location where the atmospheric conditions are known which will be used to decide the use of a particular Solar Panel. Various atmospheric conditions like Solar Irradiance, Temperature and Wind Speed affect the parameters. The various solar panel parameters include V_{OC} (Open Circuit Voltage), I_{SC} (Short Circuit Current), Maximum Power, Voltage and Current at Maximum power point V_{mpp} and I_{mpp}, Fill Factor and Efficiency. These factors vary with changing atmospheric conditions. The values of these parameters will be determined at different environmental conditions. These parameters account for the complex dependence of Solar Panel performance upon Solar Irradiance Intensity and Solar Panel Temperature. To find the above parameters, minimum data in form of the Datasheets of Solar Panels and the measured atmospheric conditions like Solar Irradiance and Panel Temperature will be required. With this data, we can predict the panel behavior by using a mathematical model representing the Panel already proposed. The mathematical model was tested on given data. All of the calculated parameters matched with the given parameters expect for the Series Resistance values which caused discrepancies in the final power values. Hence, we propose a new formula to calculate the value of Series Resistance from the values of V_{OC}, I_{SC}, V_{mpp} and I_{mpp}. This formula was tested on different solar data in different conditions. A data from January 2010 was used to calculate all the complex parameters. The data included the values of V_{OC}, I_{SC}, V_{mpp}, I_{mpp}, Temperature, Irradiance and P_{max} at different times during the day for 7 days. From the given data, two values of G and T are considered. Using the formulae, values of, and are calculated. The given values of V_{OC}, I_{SC} are used to verify the calculated values of V_{OC}, I_{SC}. Also, the values of V_{OC}, I_{SC}, V_{mpp} and I_{mpp} are used in calculating the Series resistance and in turn, the Ideality Factor. Using all these complex parameters, the value of P_{max} is calculated which is then com-pared with the given value of P_{max} in the data to verify the results**.**

II. CALACULATION OF COMPLEX PARAMETERS

A. *Calculation of α*

$$\alpha = \frac{ln\left(\frac{I_{sc0}}{I_{sc1}}\right)}{ln\left(\frac{G_0}{G_1}\right)}$$

Where I_{SC0}=6.436
G_0=749.54 W/sq m and
I_{SC1}=4.201,
G_1=500 W/sq. m
On substituting the above values we get α=1.052

B. Calculation of β

$$\beta = \frac{\frac{V_{oc0}}{V_{oc1}} - 1}{ln\left(\frac{G_0}{G_1}\right)}$$

Where V_{OC0}=25.54 V
G_0=749.54 W/sq m and
V_{OC1}=24.76 V
G_1=500 W/sq. m
On substituting the above values we get β=0.07

C. Calculation of γ

$$\gamma = \frac{ln\left(\frac{V_{oc0}}{V_{oc1}}\right)}{ln\left(\frac{T_1}{T_0}\right)}$$

Where V_{OC0}=25.54 V
T_0=315.126 K and
V_{OC1}=24.76 V
T_1=300.95 K
On substituting the above values we get γ=0.07

III. CALCULATION OF V_{OC} AND I_{SC} USING THE VALUES OF CALCULATED PARAMETERS

Now, using the values of *α, β* and γ *we* can calculate the values of I_{SC} and V_{OC}. The values of the parameters can be substituted in the equations previously defined. Thus, the values of I_{SC} and V_{OC} were calculated at different values of G and T for a given data of one day which was later extended to 7 days. The values of V_{OC} and I_{SC} were calculated for one day first. The results were compared with the given values and then the method was extended for the data of 7 days.

A. I_{SC}

$$I_{sc} = I_{sc0}\left(\frac{G}{G_0}\right)^{\alpha}$$

Where
I_{SCo}=6.436 A
G_0=749.54 W/sq. m

Using different values of G and T, the values of Short circuit current I_{SC} were found. They were compared with the values of I_{SC} in the given data and plotted with respect to time. The graph showed that the calculated and given values were almost in complete conjunction with each other with very minor deviations. This proved the method proposed to calculate the value of I_{SC}. *The graph comparing the two* I_{SC} *values for a day has been plotted below*.

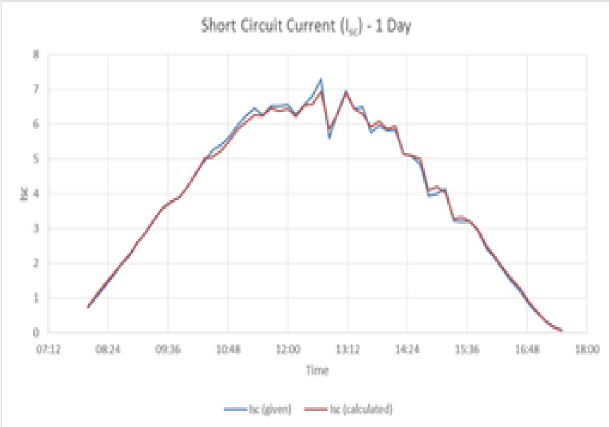

Figure 1: Comparison of given and calculated I_{SC} for 1 day

The same method was used to calculate the I_{SC} for different values of G and T across 7 days. The graph showed similar results.

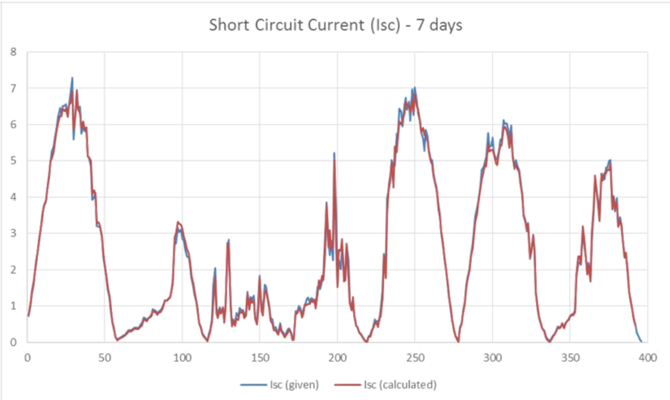

Figure 2: Comparison of given and calculated I_{SC} for 7 days

B. V_{OC}

$$V_{oc} = \frac{V_{oc0}}{1+\beta ln\frac{G_0}{G}}\left(\frac{T_0}{T}\right)^{\gamma}$$

V_{OC0}=25.54 V
G_0=749.54 W/sq m
T_0=315.126 K

Values of G and T were substituted and the values of Open Circuit Voltage V_{OC} were calculated.

They were compared with the values of V_{OC} in the given data and plotted with respect to time. The graph showed that the calculated and given values were in conjunction with each other with some deviations. Although the graph deviates from some of the values, the deviation is small. The graph is obtained with a good accuracy. This proved the method proposed to calculate the value of V_{OC}.

The graph comparing the two V_{OC} values for a day has been plotted.

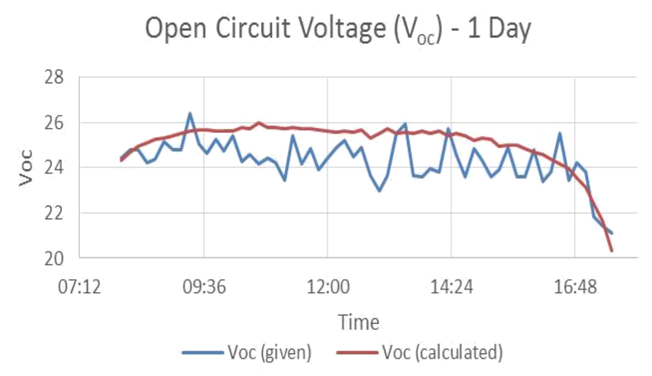

Figure 3: Comparison of given and calculated VOC for 1 day

The same method was used to calculate the V_{OC} for different values of G and T across 7 days. The graph showed similar results.

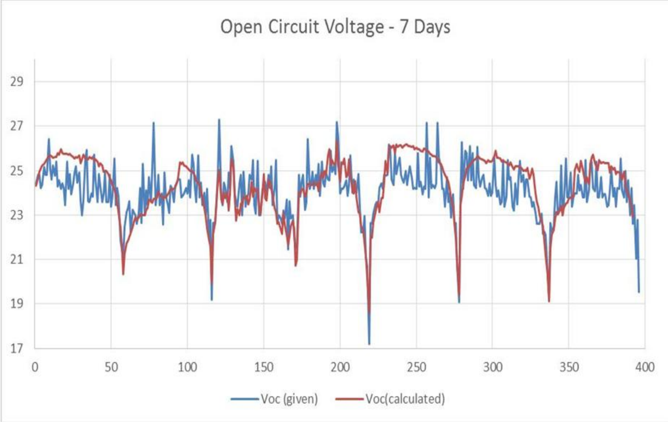

Figure 4: Comparison of given and calculated V_{OC} for 7 days

IV. CALCULATIONOF COMPLEX PARAMETERS R_S AND IDEALITY FACTOR

A. Calculation of Rs

The formula proposed by Jia and Anderson to calculate R_s is

$$R_s = \frac{V_{MPP}}{I_{MPP}} \cdot \frac{\frac{1}{V_t}\cdot(I_{sc}-I_{MPP})\cdot\left[V_{oc}+V_t\ln\left(1-\frac{I_{MPP}}{I_{sc}}\right)\right]-I_{MPP}}{\frac{1}{V_t}\cdot(I_{sc}-I_{MPP})\cdot\left[V_{oc}+V_t\ln\left(1-\frac{I_{MPP}}{I_{sc}}\right)\right]+I_{MPP}},$$

Using this formula, the values of R_s were calculated. But when the Maximum output power P_{max} was calculated using these values of R_s and compared with the given values of P_{max}, deviation was observed between the two sets of values. The P_{max} calculated using Jia and Anderson's formula for R_s was much smaller in magnitude than expected. Hence, we derive/proposed a new formula for the calculation of R_s. Firstly, we calculated the correct or expected values of R_s (which would eventually generate the correct values of P_{max} as per given data) using reverse engineering. With the help of given experimental data, the values of V_{OC}, I_{SC} and P_{max} were substituted in the equation of P_{max}.

$$P_{max} = FFV_{oc}I_{sc}$$

The only unknown in the equation was 'FF' or the Fill Factor which is given by the equation

$$FF = FF_0\left(1 - \frac{R_s}{\frac{V_{oc}}{I_{sc}}}\right)$$

In this equation, the value of FF_0 remains almost equal to constant value 1 all the time. Hence, it was approximated to be constant. Substituting the other values, the expected value of R_s was calculated for all times during the day. These values of R_s would generate the expected $P_{max.}$ Now, to derive the formula for R_s using the given data which included, V_{OC}, I_{SC}, V_{mpp} and I_{mpp} we plotted the values of V_{OC}/I_{SC}, V_{MPP}/I_{MPP} against the values of expected R_s in MATLAB. Using I_{SC} I_{MPP} the property of Curve Fitting, we found the equation relating the above 3 terms. The equation formed is given by,

$$R_s = -0.01682 - 0.0002827\frac{V_{oc}}{I_{sc}} + 0.2921\frac{V_{mpp}}{I_{mpp}}$$

Using this equation, the value of R_s was calculated by substituting the values in the equation. Thus, values of R_s were obtained at different times during the day. They were compared with the expected R_s values and a clear agreement was found between the two sets with very minor deviations. The plot of expected R_s vs calculated R_s using the formula showed a straight line which confirmed the agreement.

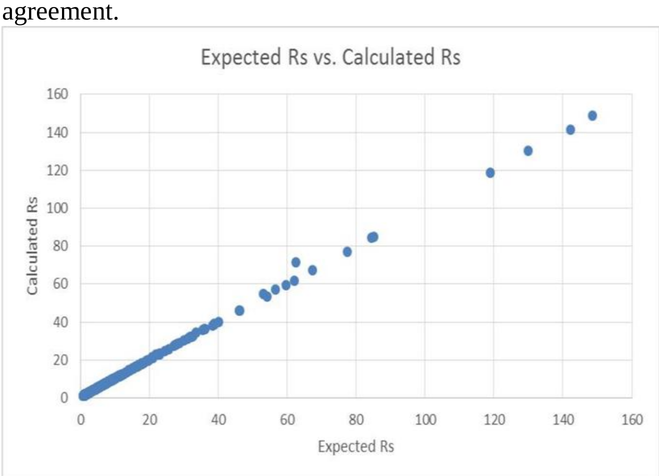

Figure 5: Comparison of expected and calculated R_s

The comparison of values of R_s calculated by Jia and Anderson's formula and by the proposed formula with the expected value of R_s can be seen below.

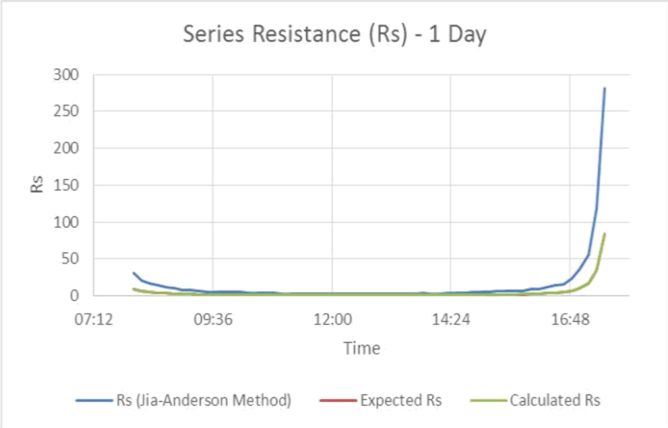

Figure 6: Comparison of values of R_s for 1 day

The graphs below show the comparison of R_s values for seven days using both the formulae.

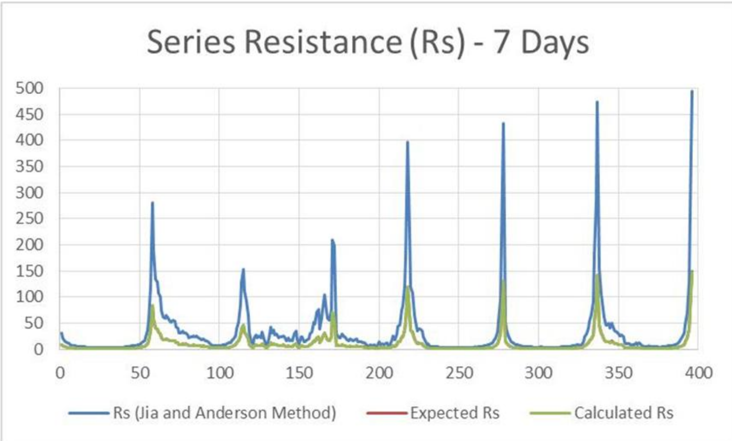

Figure 7: Comparison of values of R_s for 7 days

B. *Calculation of Ideality Factor n*

$$n_{MPP} = \frac{(V_{MPP} + I_{MPP}R_S)}{\left[V_{oc} + V_t ln\left(\frac{I_{sc}-I_{MPP}}{I_s c}\right)\right]}$$

The value of V_t was calculated by substituting the value of 'T' at different times during the day (as given in the data) in the equation

$$V_t = \frac{kT}{q}$$

Substituting the values in the above equation, we calculate the values of Ideality factor. The values of Ideality factor for a data of 1 day was calculated which was later extended for a data of 7 days. The values of Ideality factor are around 1 for the entire duration

V. CALCULATION OF FILL FACTOR AND $_{MAX}$IMUM POWER POINT P_{MAX}

A. Calculaion of Fill Factor

The value of Fill Factor is given by

$$FF = FF_0\left(1 - \frac{R_s}{\frac{V_{oc}}{I_{sc}}}\right)$$

$$FF_0 = \frac{v_{oc} - ln\left(v_{oc} + 0.72\right)}{1 + v_{oc}}$$

Where, FF_0 is the fill factor of the ideal PV module without resistive effects; R_s is the series resistance; V_{OC} is the normalized value of the open-circuit voltage to the thermal voltage, i.e.

$$v_{oc} = \frac{V_{oc}}{\frac{nKT}{q}}$$

First, the values of normalized open circuit voltage V_{OC} were calculated by substituting the value of 'n' (Ideality Factor) found out earlier.These values were then substituted in the equation of the Ideal PV Module Fill Factor FF_0. The values of the Ideal Fill Factor were found and remained almost equal to '1' as we had approximated earlier while finding the value of R_s using reverse engineering. This verified the newly obtained values of Series Resistance. Now, the values of Fill Factor were obtained by substituting the values of V_{OC}, I_{SC}, R_s and FF_0 in the equation. The Fill Factor for different conditions was found to be between 0.7 to 0.8 as per the changes in Temperature and Irradiance which in turn resulted in different values of V_{OC}, I_{SC} *and* R_s.

B. Calculation of Maximum Power Point P_{MAX}

We calculated the values of I_{SC}, V_{OC} and Fill Factor FF. We now substitute these values in the equation of P_{MAX}:-

$$P_{max} = FFV_{oc}I_{sc}$$

The expanded form of the above equation is

$$P_{max} = \frac{v_{oc} - ln\left(v_{oc} + 0.72\right)}{1 + v_{oc}}\left(1 - \frac{R_s}{\frac{V_{oc}}{I_{sc}}}\right)\frac{V_{oc0}}{1 + \beta ln\frac{G_0}{G}}\left(\frac{T_0}{T}\right)^{\gamma} I_{sc0}\left(\frac{G}{G_0}\right)^{\alpha}$$

Substituting all the values, we calculated the power. This value of P_{MAX} was calculated using the formula we proposed for R_s. This value was compared with the given P_{MAX} values and the P_{MAX} calculated using Jia and Anderson's formula for R_s. This plot confirmed that the method proposed in this project gives more accurate values of P_{MAX} as compared to the other methods as the curve of calculated P_{MAX} using our method traces the curve of given P_{MAX} with very minor deviations as compared to the other curve. The plot of P_{MAX} comparison for 1 day and 7 days is given below

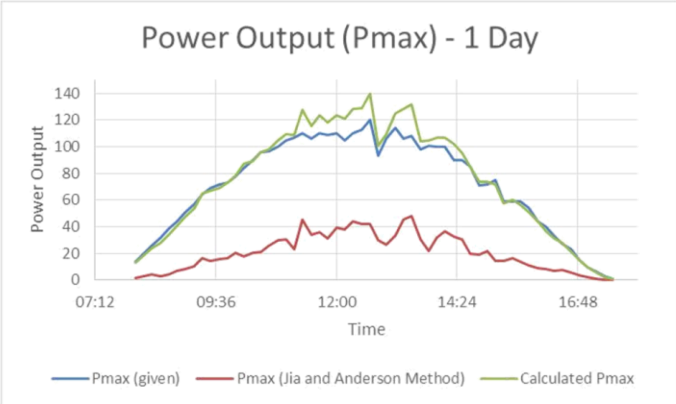

Figure 8: Comparison of values of P_{max} for 1 day

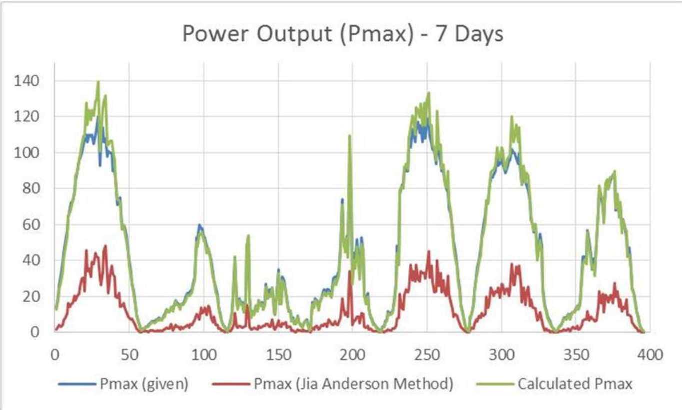

Figure.9: Comparison of values of P_{MAX} for 7 days

VI. CALCULATION OF P_{MAX} FOR DIFFERENT SET OF data

The proposed formula for R_s was tested for an altogether different solar panel data for a different day, different weather conditions and different solar panel. The same sequence of steps was followed to get the values of V_{OC}, I_{SC}. The value of R_s was calculated using the new formula. From this value, the values of Ideality Factor, Fill Factor and eventually P_{MAX} were calculated. These values of P_{MAX} were tallied with the given P_{MAX} and an agreement was observed with minor deviations. Hence, the data calculated by our proposed formula was tested for different conditions and the results matched every time. Hence, we proposed the new formula for R_s.

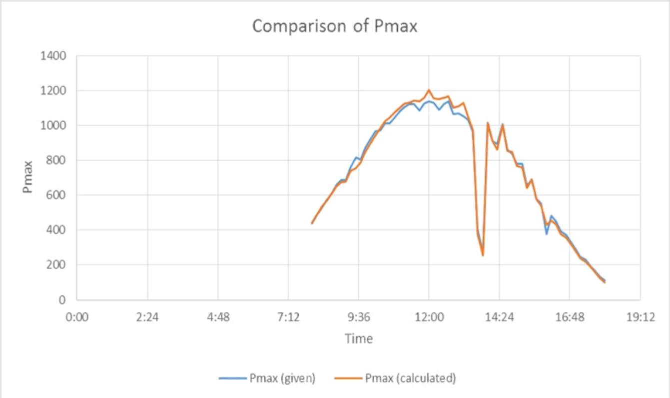

Figure 10.Comparison of values of P_{MAX} for different data

VII. CONCLUSION

- Using the mathematical model proposed, the values of various panel parameters were obtained.
- After calculating the values of α, β, γ the Series resistance and open circuit voltage values were calculated. The calculated values of V_{OC} and I_{SC} matched with the values of V_{OC} and I_{SC} in the given data.
- The values of Fill Factor and Maximum power were calculated but variations were found with these and the values in the given data because of the di$_{sc}$repancies in the calculated values of Series Resistance R_s.
- Hence, a new formula was proposed to calculate the value of R_s. This formula was derived using reverse engineering and curve fitting methods.
- Using the new formula, the calculated values of R_s were obtained. These were used to find the Fill Factor and maximum power.
- The newly calculated values matched with the required data.
- The same formula was tested on other data to verify the results. The calculated values matched with the given data in this case too.
- Very minor and negligible di$_{sc}$repancies were found in the answers unlike the case of the earlier proposed mathematical model.
- Hence, a new formula has been proposed to calculate the values of Series Resistance R_s using the values of V_{OC}, I_{SC}, V_{MPP} and I_{MPP}.
- With the incident data available at a particular place, the output power of the panel at all the time during the day can be found out.

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