Theoretical Analysis of the Series Parasitic Resistance in Photovoltaic Cell

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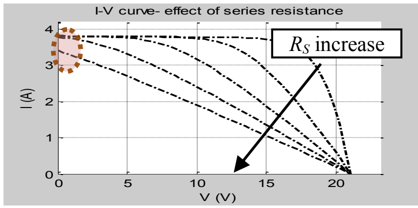
***Abstract*—An accurate estimation of the series resistance in the PV model is crucial to the prediction of the maximal output power of the PV module, especially under temperature variation. This Paper proposes a theoretical expression to calculate accurately the value of this resistance. The proposed expression comes from the physical nature of the various elements constructing this resistance, plus the reverse relation of the output power with cell temperature, utilizing manufacturer datasheet only. The proposed expression was tested against experimental measurements and previous work, showing a clear improvement in tracing the series resistance values under varying temperature.**

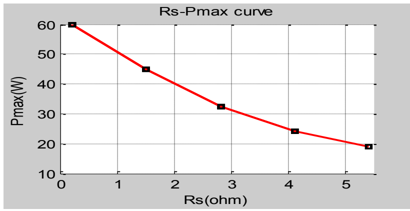
***Keywords*—PV cell; parasitic resistance; series resistance; parameter extraction**

I. INTRODUCTION

The fast development in the solar cell production field implies an increase in the area of the PV cell and hence its finger length, leading to an increase in its series resistance and the power loss due to this resistance [1]. Alternatively, the thermal effect due to the daily exposure of the PV module to sunlight, results in a gradual increase in series resistance R_S of the PV module, decreasing the maximum output voltage V_m, the maximum output current I_m, and hence the maximum output power of the solar cell. A further increase in the value of this resistance results in a decrease in the short circuit current I_{SC}, as shown in Fig. 1-a. Moreover, there is an inverse relationship between the value of the maximum output power P_{max}, of the PV module and the value of its series resistance, which in terms causes a reduction in fill factor of the PV cell ($FF = P_{max} / I_{SC} V_{OC}$) as well as the efficiency of the PV cell ($\eta = P_{max} / P_{in} = FF\, I_{SC} V_{OC} / P_{in}$) as shown in Fig. 1_b, Fig. 1_c respectively, in addition to Table 1. Table 1 shows that an increment of about 1.3Ω in the series resistance each time causes a percentage of 10% to 25% of losses in both the maximum power and the fill factor. This shows the crucial role played by the series resistance on the performance of the PV system.



(a)



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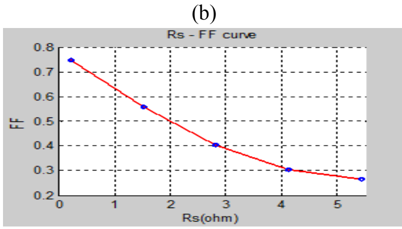

(c)

Fig. 1. The effect of the series resistance R_S on the output power and fill factor of the PV module (a) effect of the incremental value of the R_S on the I-V curve (b) The R_S value and the output power relationship (c) the influence of R_S value on the fill factor of the PV module

Table 1: The effect of the series resistance on the short circuit current I_{SC}, the maximum output power P_{max}, and the fill factor FF of the PV module

R_S (Ω)	I_{SC}(A)	P_{max}(W)	FF	(%) loss in	
				P_{max}	FF
0.217	3.800	59.787	0.7456	---	---
1.519	3.790	44.79	0.558	25.08	25.16
2.821	3.790	32.41	0.404	46.8	45.82
4.123	3.760	24.167	0.304	59.28	59.23
5.425	3.396	19.014	0.265	59.34	64.46

The effect of the series resistance on PV module performance is significant, where neglecting this resistance over a full range of operating conditions lowers the predicted maximum output power from 5% to 8% than if the correct value is used [2]. This value is crucial when employing PV modules in systems and when analyzing performance degradation [3, 4]. Various methods were introduced to measure this resistance [5, 6]; however a theoretical expression of this resistance is not accurately established yet.

II. ANALYSIS OF SERIES RESISTANCE

The output power of the PV module decreases with the increase in cell temperature, which implies that [7]

$$\frac{dP}{dT}=\left\{\frac{2I^2R_L\chi_o e^{\chi}}{1+\chi_o e^{\chi}}\left(\frac{1}{T}-\frac{1}{(R_L+R_S)}\frac{dR_S}{dT}\right)\right\}<0 \tag{1}$$

With the implicit condition that R_L and Φ are constant to the temperature T ($dR_L/dT=0$, $d\phi/dT=0$), where:

$$\chi_o=\frac{qI_o(R_L+R_S)}{akT} \tag{2}$$

$$\chi=\frac{qI(R_L+R_S)}{akT} \tag{3}$$

$$I=m\phi-I_o\left(e^{\chi}-1\right) \tag{4}$$

where I is the current density under uniform illumination, m is the photoelectric conversion factor, ϕ is the illumination intensity, I_o is the reverse saturation current density, R_L is the load resistance, R_S is the series resistance, k is the Boltzmann constant, T is the absolute temperature, q is the elementary charge, a is the diode ideality factor.

Due to [7]

$$\frac{2I^2R_L\chi_o e^{\chi}}{1+\chi_o e^{\chi}}\frac{1}{T}>0 \tag{5}$$

and to satisfy the condition mentioned in Eq. (1), R_S has to be relevant to T, which implies that $dR_S/dT\neq 0$.

Ding et al. [7] shows that the series resistance can be represented by the semi-conductor positive temperature coefficient type of thermal resistance. While, the series resistance in the PV cell is a combination of the components that come in the path of the current, such as the base resistance, the emitter resistance, metal contact resistance, et cetera. This implies that the series resistance is a combination of conductor type and semi-conductor type of materials, which are two different types of thermal sensitive resistances. Based on this fact, a theoretical definition of the series resistance is going to be discussed in the following.

$$R_{ST}=\underbrace{R_{OC}(1+\alpha T)}_{R_{SC}}+\underbrace{R_{OS}e^{\beta T}}_{R_{SS}} \tag{6}$$

Where R_{ST} is the total series resistance, R_{SC} is the conductor type part of R_{ST}, R_{SS} is the semi-conductor type part of R_{ST}, α and R_{OC} are the conductor temperature coefficient and condition resistance respectively, while β and R_{OS} are the semi-conductor positive material coefficient and the condition resistance respectively. From Eq. (6)

$$\frac{dR_S}{dT}=\alpha R_{OC}+\beta R_{SS} \tag{7}$$

Substituting in Eq. (1)

$$\frac{dP}{dT}=\frac{2I^2R_L\chi_o e^{\chi}}{1+\chi_o e^{\chi}}\left(\frac{R_L+R_{OC}+R_{SS}-\beta R_{SS}T}{T(R_L+R_{ST})}\right) \tag{8}$$

To satisfy the condition in Eq. (1), it require that

$$\beta>\frac{1}{T}\left(1+\frac{R_L+R_{OC}}{R_{SS}}\right)>0 \tag{9}$$

This agrees with the definition of the semi-conductor material coefficient $\beta>0$. Therefore, the series resistance can be declared as a combination of conductor and semi-conductor type of resistance, which agrees with the physical construction of the PV cell.

On the other hand, under a range of temperature, the resistivity of the semi-conductor material could be described by [8]

$$R_{SS}=R_{OS}(1+\beta T) \tag{10}$$

Hence the resistance/temperature coefficients are of the order 0.004 per ºC for pure metals, and less than 10^{-4} per ºC for certain alloys, and might be of zero value between 0 ºC and 40 ºC [8], the change in the resistance of the metal contacts, with respect to temperature variation, can be neglected. Assuming equal values of R_{OC} and R_{OS} under STC and utilizing the variation in temperature, Eq. (6) can be written as follows;

$$R_{ST}=R_O(2+\beta\times\Delta T) \tag{11}$$

where $\Delta T=T-T_n$; T_n = 298.15 ºC is the temperature under STC, T is the current cell temperature, and R_O is the condition resistance.

This expression can be used in the parameter extraction of the PV model [9, 10], to improve the accuracy of the two-diode model especially when subjected to temperature variation.

III. RESULTS AND DISCUSSION

Utilizing the solver tool in Microsoft Excel program and the LabVIEW 2012 software, the theoretical expression of the series resistance shown in Eq. (11) is fitted to the experimental values of R_S and validated against the calculated values from [7], as shown in table (2). Fig. 2 shows the graphical representation of table (2), where the sum of standard deviation shows a superior representation of the proposed expression against [7]; where the sum of standard deviation is reduced from 1.338E-7 in [7] to 1.743E-11. On the other hand, Fig. 3 shows a comparison between the absolute errors produced by [7] and the proposed expression, which shows a recognizable improvement utilizing the proposed expression. Fig. 4 shows the resultant absolute error and standard deviation of the simulated values. While Fig. 5 shows the LabVIEW model used to model the theoretical expression of the R_S model against the experimental data, which can be inserted in the PV module model to get its output under varying temperature.

TABLE 2

Experimental against calculated data of the silicon solar cell utilizing [7] and the proposed model

T (K)	R_S (Ω)	Ref [6] (Ω)	Model (Ω)
303	0.02817	0.02848	0.02817
313	0.0298	0.02989	0.02980
323	0.03143	0.03138	0.03143
333	0.03306	0.03293	0.03306
343	0.03469	0.03457	0.03469

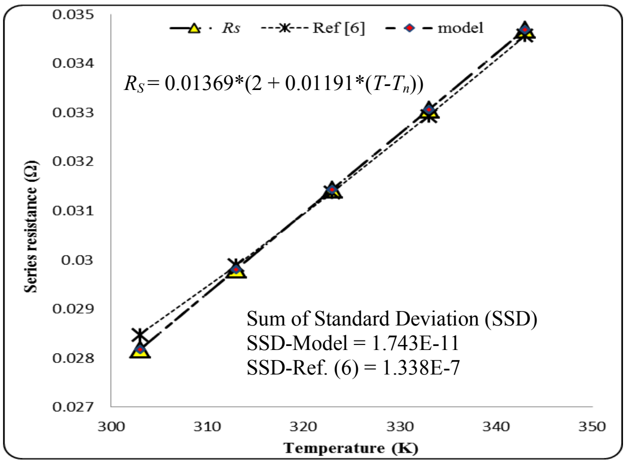

Fig. 2 Fitting curve of the actual silicon solar cell series resistance against [7] and the proposed model

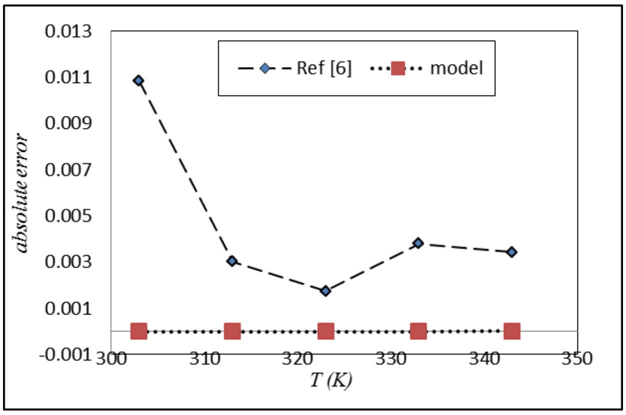

Fig. 3 The absolute error of the proposed model and [6] under variable temperature

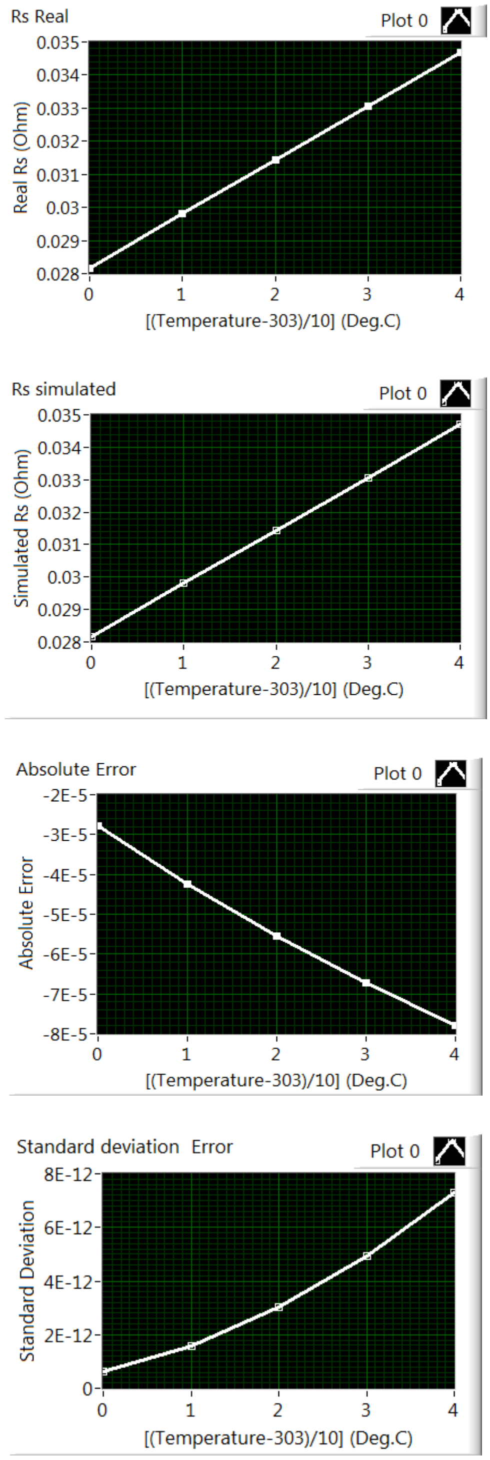

Fig. 4 The real R_S values, the predicted R_S values under varying temperature, plus the absolute error and the standard deviation between real R_S and simulated R_S.

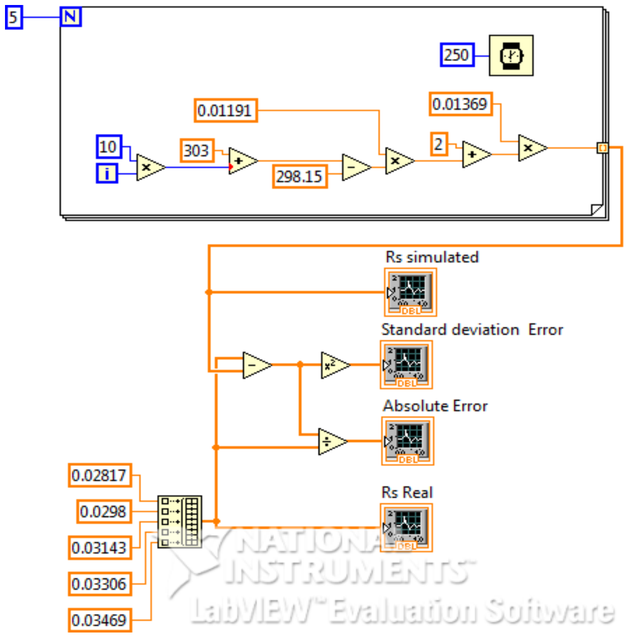

Fig. 5 LabVIEW model utilized to calculate R_S value under varying temperature levels.

IV. CONCLUSION

This paper gives a theoretical expression of the series resistance that coincides with the physical nature of its components. The proposed expression shows an excellent ability in matching the experimental values of this resistance under temperature variation, which is useful to the PV model designers.

ACKNOWLEDGMENT

The authors wish to acknowledge the support provided by Universiti Teknologi PETRONAS, Malaysia to complete this work successfully.

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