Analysis of the heat sink effect on parasitic resistances of photovoltaic modules based on inverse slope method

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ABSTRACT: In analyzing photovoltaic (PV) performance due to heat sink cooling, the effect of parasitic resistance is often neglected. Indeed, these resistances are highly dependent on temperature variation and negatively influence by reducing fill factor (FF). Hence, this paper examines the effect of heat sink cooling on both series and shunt resistances. The outdoor experimental setup consists of two 120 Wp monocrystalline PV modules; one served as a reference module for comparison against the module with heat sinks. The other one was attached with the cooling heat sinks. The performance parameters were recorded and analyzed using a current-voltage curve tracer and weather monitoring station. The results showed an improvement in R_{sh} and R_s by 5.39 % and 0.89 %, respectively. The increase in shunt resistance may reduce the probability of hotspot formation.

Keywords: *Series and shunt resistance; PV cooling*

1. INTRODUCTION

Solar photovoltaic (PV) absorbs 80 % of incident solar irradiance, but only 20 % is transformed into electricity [1]. The remainder part wasted as heat, causing an unwanted increase in module temperature. The elevated module operating temperatures highly influences the decrease in voltage and power conversion efficiency (PCE). Depending on the specific PV technology, the percentage of temperature degradation ranged from 0.25 %/ºC to 0.5 %/ºC and was defined as temperature coefficient.

Various efforts have been conducted to investigate the effect of temperature and solar irradiance on the performances of PV modules [2], [3]. However, accurate analysis of PV performances should consider the non-linear behavior of parasitic resistances. In [4], a two diode equivalent model is used to comparatively quantify the effect of parasitic resistances comparing two different PV module technologies. Nonetheless, very few studies have investigated the influence of fin heat sinks on the parasitic resistances of the PV module. This work, however, investigating its influences by applying the inverse slope method based on the real experimental data obtained from the I-V measurements.

2. METHODOLOGY

2.1 Conditions with real solar cells

The current generator I_{ph} is connected in parallel with a diode to represent the P-N junction, defined by a simplified PV cell equivalent circuit. Concerning the real solar cell behavior, two parasitic resistances, namely series and shunt resistances, are considered for accurate characterization. The role of R_s and R_{sh} in solar cells can be expressed as follows [5]:

$$I = I_0.\left[exp\left(\frac{q.[V-I.R_S]}{k_B.T}\right)-1\right]-I_{sc} \quad (1)$$

and,

$$I = I_0.\left[exp\left(\frac{qV}{k_B.T}\right)-1\right]+\frac{V}{R_{sh}}-I_{sc} \quad (2)$$

where I_o is saturation current, I_{sc} is the short circuit current, q is the electron charge, k_B is the Boltzmann's constant, T is the absolute temperature, R_s is series resistance, and R_{sh} is shunt/parallel resistance. R_s dominates at $I \rightarrow 0$, while R_{sh} dominates at $V \rightarrow 0$. Both R_s and R_{sh} can be determined based on the inverse slope method, as follows:

$$R_s = -\left(\frac{dV}{dI} - \frac{\left(\frac{kT}{q}\right)}{I_{sc}}\right)_{at\ open-circuit} \quad (3)$$

$$R_{sh} = -\left(\frac{dV}{dI}\right)_{at\ short-circuit} \quad (4)$$

2.2 Measuring parasitic resistances

In this work, the inverse slope method is used to determine the parasitic resistances based on the measured I-V curves for both PV modules (with and without cooling heat sink). The experimental setup is presented in Figure 1, including all hardware instruments, parameter extraction, and data acquisition control unit. The current-voltage characterization was performed outdoors (2.2699° N, 102.2945° E) under realistic operating conditions to yield more accurate data. The experimental measurements were taken every hour from 9:00 a.m. to 05:00 p.m and tested on 23-29th April 2021.

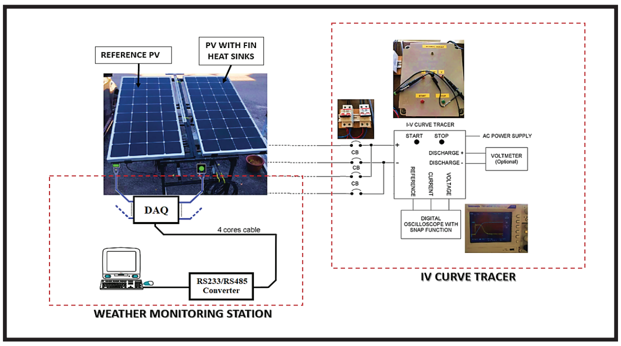

Figure 1 The experimental setup

3. RESULTS AND DISCUSSION

From the data collected, performance parameters (I_{mp}, V_{mp}, I_{sc}, V_{oc}) for both PV modules were determined based on IV characteristics and further analyzed to investigate the effect of parasitic resistances (R_s and R_{sh}).

3.1 The heat sink effect on series resistance, R_s

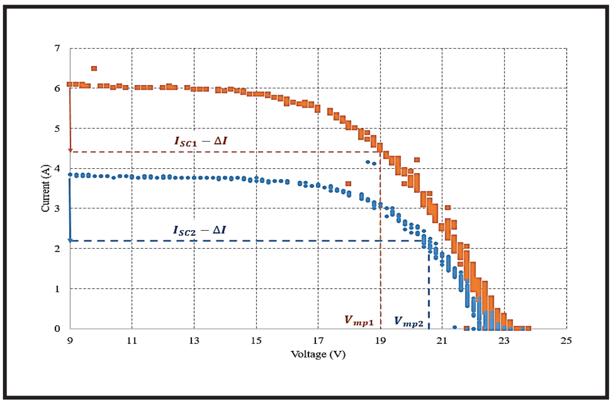

Figure 2 *IV* characteristics for determination of R_s

The occurrence of series resistance R_s is mainly due to the resistances in the emitter-base regions, metallization contacts, and cell-interconnect busbars. Based on Figure 2, the R_s is reduced with the help of the fin heat sink allowing more current to flow through the load, thus enhancing the power output.

3.2 The heat sink effect on shunt resistance, R_{sh}

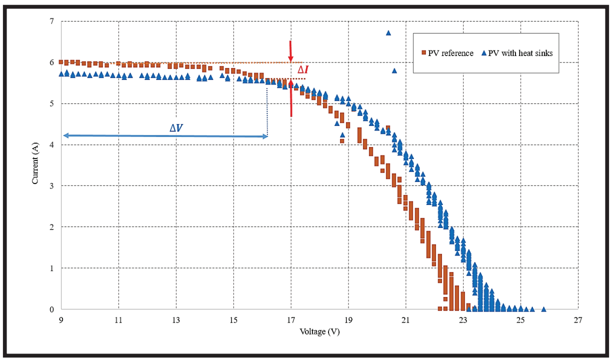

Figure 3 *IV* characteristics for determination of R_{sh}

The shunt resistance, R_{sh}, represents the high-conductivity paths across the solar cell p-n junction. Figure 3 illustrates the influence of shunt resistance on the cooling heat sink. It is observed that the PV module with heat sink improved the shunt resistance by leading more current to flow through the intended load, indicates by higher values of V_{oc}.

Table 1 Measured PV module parameters.

	PV without cooling heat sink	PV with cooling heat sink
I_{mp} (A)	4.96	5.12
V_{mp} (V)	18.2	19.1
I_{sc} (A)	6.08	5.96
V_{oc} (V)	22.8	24.0
R_s (Ω)	0.798	0.791
R_{sh} (Ω)	0.815	0.859
FF	**0.651**	**0.683**

4. CONCLUSIONS

This study investigates parasitic resistances on the PV module performance when the cooling heat sink is attached at the rear side. The results show that the PV module with the cooling heat sink can improve the shunt resistance, Rsh, and series resistance, Rs by 5.39 % and 0.89 %, respectively, compared to the bare PV module. A significant increase in R_{sh} is desired to avoid the high current flowing through parasitic resistances and results in the formation of hotspots. As a result, the maximum power output is increased.

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