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Method for module R_{sh} determination and its comparison with standard methods

Eduardo Forniés [a,*], José Lorenzo Balenzategui [b], María del Carmen Alonso-García [b], Jose Pedro Silva [b]

[a] Aurinka PV Group SL, R&D Department, C/Marie Curie 19, 28521 Madrid, Spain
[b] CIEMAT—División de Energías Renovables, Av. Complutense 22, 28040 Madrid, Spain

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Abstract

A method to characterize the module shunt resistance (R_{sh}) by measuring the module at reverse bias and dark conditions connected to an external parallel resistance is presented. For the purpose of proving this method, two modules, MA and MB, with the same type of cells, but different shunt resistance, were manufactured. The R_{sh} values as determined by the proposed method have been compared with those obtained by commercial flash solar simulators and other standard procedures. Additionally, modules MA and MB were measured at different irradiance levels to relate the R_{sh} with the module performance at low irradiance conditions. Finally, in order to evaluate the relative importance of a correct determination of the module R_{sh}, a simulation of Annual Energy Yield obtained with an installation made with modules MA compared with modules MB have been carried out by means of PVsyst program.

Keywords: Shunt resistance; Parallel resistance; Solar cell; PV modules; Efficiency; Characterization

1. Introduction

In recent years photovoltaic energy has become an established alternative energy source. Several reasons have contributed to this; the decreasing of production costs of all the materials and processes along the manufacturing chain, the increasing of cell and module efficiency and a noticeable improvement of the reliability and lifetime of PV modules.

In particular, the decreasing of series resistance, R_s, and the increasing of shunt or parallel resistance, R_{sh}, have had a direct influence on that efficiency improvement. This paper focuses on the study of the correct determination and the effects of shunt resistance (R_{sh}) of PV modules.

The physics, modeling and performance of solar cells working under reverse bias conditions has been previously reported (Blake and Hanson, 1969; Alonso-García and Ruiz, 2006; Danner and Bücher, 1997; Hartman et al., 1980; Spirito and Abergamo, 1982; Lopez Pineda, 1986; Bishop, 1988). In conventional crystalline silicon solar cells, current shunts result from any path that bypasses the *p–n* junction, directly through it or through the defective isolated edges of the cell. When one or some cells inside a module are working at a lower current level because of mismatch, breakage or shadowing, the excess of current produced by the rest of the cells is forced to pass through

* Corresponding author. Address: Aurinka PV Group, Marie Curie 19, Building II, Office 2.2, Rivas-Vaciamadrid 28521, Madrid, Spain. Tel.: +34 649432841.
E-mail address: efornies@hotmail.com (E. Forniés).

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the parallel resistance of those cells (Swaleh and Green, 1982), making them to work under reverse bias conditions.

Thus, the shunt resistance has become one of the most concerning parameters for the PV industry, in particular, for its direct influence on the formation of hot spots (Alonso-García and Ruiz, 2006; Simon and Meyer, 2010). The hot spot becomes more destructive when the module R_{sh} is low because the shunt is normally localized in a small area (Herrmann and Wiesner, 1988; Langenkamp and Breitenstein, 2002; Hermann et al., 2001; Alonso-García et al., 2003), leading to a defective heat dissipation and consequently to a rapid increase of the temperature which can permanently damage the materials of the module (cells themselves, backsheet, EVA, etc). Moreover, in case of a shadowed cell, the bypass diodes could eventually not be activated due to the low resistance of shunts, leaving the module without protection (Danner and Bücher, 1997).

The shunt resistance is also a good indicator of the electrical performance of solar cells under low irradiation conditions (McMahon et al., 1996; Grunow et al., 2004; Müller et al., 2010; López et al., 2010; Breitenstein et al., 2004), obtaining smaller values of efficiency at low irradiation (<600 W/m^2) for decreasing values of shunt resistance. This issue can lead to a high cumulative loss of power along the year, especially in countries with low irradiation conditions.

For those reasons, the correct determination of R_{sh} in solar cells and modules has become a topic of undeniable importance to avoid the above mentioned problems. In the case of individual solar cells, R_{sh} can be determined, for example, by numerical fitting, simulation or modeling, using different analytical solutions proposed in the literature based either on the single-diode model (Swaleh and Green, 1982; Chen et al., 2011; Priyanka Lal and Singh, 2007; Bouzidi et al., 2007; Merhej et al., 2009; Adamo et al., 2009; Charles, 1981; Benghanem and Alamri, 2009; de Blas et al., 2002), or on the two-exponentials model (Merhej et al., 2009; Radziemska, 2005; Ishaque et al., 2011; Bühler and Krenzinger, 2013).

The problem enlarges in the case of PV modules because, once the cells are associated in series to form a module, the R_{sh} of every solar cell is added (Alonso-García, 2005) and the R_{sh} value of the module can mask the low R_{sh} of a particular cell inside the module. Thus, the determination of the module R_{sh} does not allow the identification of an uneven cell within the module, or the detection of a cell that is likely to produce hot spots. To overcome that difficulty, some authors studied the R_{sh} determination of individual solar cells once they are inside a module by partial or total shading of the cell in question (De Bernardez et al., 2005; Alonso-García et al., 2006; d'Alessandro et al., 2011; Alers et al., 2011).

Additionally, as commented before, for a PV module manufacturer, it is of great importance to know the R_{sh} of the module to predict the behavior of that module at low irradiation conditions. In that sense, several authors proposed methods for module parameters extraction including the R_{sh} (Wang et al., 2011; King et al., 1997). At a commercial level, the measurement of module I–V curve with flash solar simulators is the most common way to give a R_{sh} value in manufacturing production lines. Usually R_{sh} is calculated from the slope of the I–V curve close to I_{sc} in direct bias and under illumination conditions. Nevertheless, as it will be discussed below, the value of R_{sh} given by commercial equipments could not be reliable mainly because the module flash solar simulators (also known as flash tester) do not have the needed resolution for measuring low levels and/or small differences of current.

In this paper, an experimental method for module R_{sh} determination, based on measuring the module at reverse bias and dark conditions connected to an external parallel resistance, is presented and validated. First, a theoretical background about the determination of R_{sh} from the one- or two-diode equations is presented. After giving some details about the preparation of the module samples, their R_{sh} is calculated by standard methods. The new approach for the determination of R_{sh} is then founded and its results are compared to the previous ones. Finally, in order to study the influence of the correct determination of R_{sh} on the possible losses in the Annual Energy Yield (AEY) at the PV plant level, the performance of the samples at different irradiances has been measured and AEY is calculated by means of PVsyst software. However, the study of R_{sh} in relation with hotspots formation is out of the scope of this work.

The contents of this work could be of importance both, for researchers, because it provides an alternative way for the empirical evaluation of the module shunt resistance not dependent on simulation or fitting results, thus reducing the uncertainty in the determination of other parameters, and for industrial quality control, because the proposed procedure could be easily implemented (also in an automated form) in module production lines.

2. Theoretical background

As commented before, methods reported for the determination of the R_{sh} are based on fitting experimental I–V curves to one- or two- exponential models, or on evaluating the slope of particular intervals of the curve. For example, King et al. (1997) applied the two diode model on dark I–V forward curves, using their shape and linearity at different current levels to determine electrical parameters such as series resistance, shunt resistance, diode factor and saturation current. Nevertheless the proposed method showed low accuracy in R_{sh} determination. Several authors have approximated the R_{sh} to the inverse of the slope of the I–V curve at I_{sc}, ($R_{sh} = R_{sh0}$) Bühler and Krenzinger (2013); Wang et al., (2011).

In any case, calculation of R_{sh} both, from the slope of the I–V curve or by fitting methods starts from the description