Multiphysics and multiscale modeling of a photovoltaic panel using Monte Carlo methods

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The optical, electrical and thermal performance of a photovoltaic panel under real conditions is the result of a complex interaction between the panel and its environment: intermittent solar radiation, airflow fluctuations, and possible shading [1]. The design and performance assessment of PV cells performed under the Standard Test Conditions (STC) corresponds to a situation where the incident solar radiation power density is 1000 W.m^{-2} (AM-1.5 solar spectrum) and the cell temperature is equal to 25 °C. However, it was observed that photovoltaic panels are almost always operating far from the STC conditions in a realistic environment [2]. Therefore, it seems necessary to rethink the modeling chain of a photovoltaic panel in real operating conditions. This modeling chain requires the development of electrical, optical and thermal models involving multiphysics and multiscale coupling issues (from the cell to the solar plant).

First, a macroscopic model of the heat balance of a 310 W photovoltaic panel was developed in a probabilistic way and solved by the Monte Carlo (MC) method [3]. An estimation of the temperature at the backside of the panel was obtained and validated against experimental data (Figure 1). This method also allowed to evaluate the electrical production over a large period of time (from one day to the lifespan of a PV panel) by considering varying meteorological parameters (one minute time step).

Second, in order to develop a unified framework for the multiphysics multiscale model of the panel, a probabilistic opto-electrical model for the photovoltaic cell was elaborated. As a first stage, this model was developed by assuming that minority carriers can be separated in a simple crystalline silicon PN junction and by solving for their diffusion-generation-recombination. The total current is expressed as the sum of the photocurrent and the diode current. The total current was calculated (Figure 2) by implementing two different algorithms describing random walks either on a reverse (back to the source of electron-hole pairs) or a direct (starting from the source) path space, exhibiting two viewpoints for the analysis of the physics involved.

We will emphasize the benefits of this path space formulation: renewed physical images, insensitivity of computation times to the dimension of the integration domain (here to the number of coupled phenomena and temporal fluctuations at different scales: from the minute scale to the day, the season, the climatic scales) and to the geometrical complexity at all scales, sensitivity calculation [4], symbolic Monte Carlo [5]. This work is part of a strong dynamic of the EDStar group [6], whose research works focus on both methodological and application-related issues.

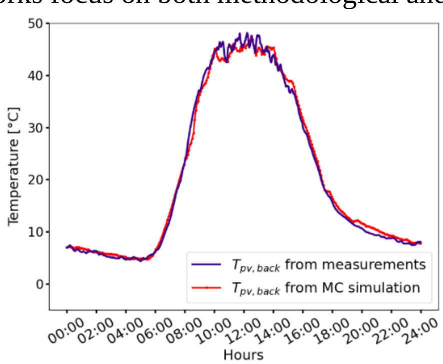

Figure 1: Comparison of the simulated temperature at the center of the rear side (red line) and the temperature from the measurements (blue line) of a 310 W panel in real operating conditions.

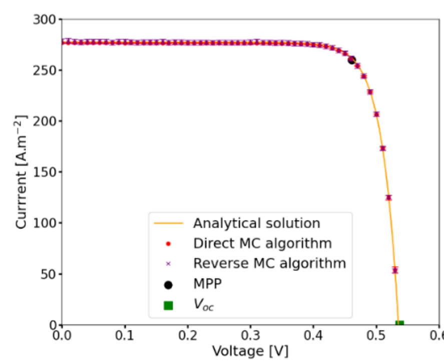

Figure 2: I-V curve of the photovoltaic cell obtained by two Monte Carlo algorithms (direct and reverse) and validation with an analytical solution. The MPP is also obtained using a symbolic Monte Carlo.

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