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Irradiance, thermal and electrical coupled modeling of photovoltaic panels with long-term simulation periods under service in harsh desert conditions

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Abstract

Predicting the electrical yield of photovoltaic (PV) devices over long periods of operating conditions is essential for the cost assessment of projects. The presented modeling of a PV panel couples different physics using finite-element method, focusing on long-term operations under desert conditions. The coupled physics are: (i)the solar irradiance; (ii)the heat transfer within the module, influencing the temperature-dependent conversion efficiency; and (iii)its electrical yield. The thermal behavior of a PV panel and predictions of its electrical yield are investigated for several years of atmospheric conditions in Saudi Arabia, with elementary assumptions regarding the performance of the selected PV device.

Keywords: photovoltaics (PV), long-term simulation, solar irradiance model, finite-element method (FEM), PV module power conversion efficiency

1. Introduction

Sun harvesting devices such as photovoltaics (PVs) are the sustainable challengers in the current energy market. Yet, their performance and long-term behavior are difficult to model so to accurately predict the life-cycle yield expected by these photo-converting devices.

Whatever the strategy to manufacture and deploy PV technologies cheaper, by tackling cell efficiency and/or module design, the optimization of their efficiency can proceed by successive small increments. Such approach is particularly effective using modeling and simulation techniques, since they can inexpensively explore intricate phenomena that are difficult to interpret. In this way, various simulation tools are useful to the PV industry in order to improve the solar cell intrinsic performances (SENTARUS, ATLAS, MICROTEC, PC1D, SCAP1D, DESSIS and their multidimensional versions – see [1] for crystalline silicon solar cells).

Beyond the scale of the solar cells and their materials to be optimized, we consider here PV panels where the cells are laminated into modules. The present study contributes to further develop prediction tools for the design of PV panel. There exist, in the literature, general performance models that deal with the yield at the PV module or array level [2–6]. For the solar irradiance input, these models can rely on: irradiance measurements (wavelength-based or fully integrated), standards data [7], solar irradiance codes such as clear sky models [8–10], SMARTS software [11], or on the circumsolar irradiance reported by [12, 13].

It is well established that the thermal behavior of the PV devices influences the yield of most of the PV technologies. This is of particular importance in regions with hot climate such as in the Middle East region. Thermal modeling is a part of multi-physics approaches, which have been used by several authors for the applications to real cases of operating conditions [3, 6, 14–20].

In the current study, we investigate such atmospheric conditions' simulations by modeling the thermal effect applied to poly-crystalline silicon PV technology. In the study, we used environmental data (solar irradiance, ambient temperature and wind speed) for 3 years and we simulated the temperature development of a selected silicon PV panel. We also simulated the electrical yield of the PV panel.

2. Experimental data and methods

Throughout the current study focusing on long period of service simulations, the modeling of the yield of PV panels in terms of electrical power has been conducted relying at first on the photo-conversion using a transformed solar experimental irradiance. This transformation modeling is mainly described in §2.2, after the application of some processes to screen out the collected data, see §2.1.

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