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Improvement and experimental validation of a simple behavioural model for photovoltaic modules

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ABSTRACT

The purpose of this work is to: 1) improve a previously developed behavioural model (B-model) for photovoltaic modules and 2) validate it using experimental data. The major advantages of the new model are its simplicity and the fact that it is based only on the module's electrical properties available on the manufacturer's datasheet. At first, the original model was developed and validated using a rich experimental database solely for a polycrystalline silicon photovoltaic module. However, an improved version of this model along with validation tests which use a larger database is presented in this paper. The larger database utilises the measured *I–V* characteristics of three other photovoltaic technologies such as, monocrystalline silicon, CIS and CdTe. To permit a sound and relatively easy entry into the study of photovoltaic for novices and newcomers, a detailed flowchart and description of its use are presented. Also a concrete example of an application using the flowchart is presented to display its efficiency and ease of use.

1. Introduction

Today, the importance of numerical simulation cannot be denied as well as its spinoff effects on numerous fields. This is especially true for research and industry. Numerical simulation is an indispensable experimentation tool as it permits the study of individual units, systems, phenomena, and projects in a relatively short time frame, without risk and at lower costs. It is clear that the accuracy and the reliability of numerical simulations depend on the efficiency of the models and methods used. This explains the continued infatuation for numerical development tools in many areas. The renewable energy field, especially photovoltaic, does not escape this rule.

Much research has been conducted and published on different topics in relation to PV modelling. The following studies do not comprise an exhaustive list of PV module/solar cell modelling topics and are provided as examples. Solar cells and PV modules modelling are still generating considerable interest with the aim to develop new materials/processes and solar cells/PV modules with higher conversion ratios at lower costs. Most of the work undertaken in this research axe can have one of the following aims: new PV material modelling [1–3]; solar cell modelling [4–11]; PV module modelling and characterisation [12–19]; PV module efficiency and energy rating [20–22]; and the study, analysis, and modelling of different factors which influence PV module and solar cell behaviour over their lifetime [23,24]. Many other components of PV systems have been studied, described, modelled, and simulated in a large number of research papers. For example, inverter [25–28], batteries [29–31], or motor–pump subsystem [32–34].

The photovoltaic array is the first component placed at the input of the PV conversion chain, since it assures the conversion of the sun irradiance to electricity. Because of this, it is obvious that its model is one of the "must have" tools to achieve any numerical simulation of photovoltaic systems and projects. Several models for PV arrays and modules have been developed to determine the exact current and voltage relationship. The most important differences existing amongst them are their degree of complexity and their efficiency. Many papers [35,36] present a detailed and rich state-of-the art of the existing models for PV modules and arrays.

Designers and students need a reliable and a simple tool to simulate photovoltaic modules input–output behaviours under all conditions to expeditiously complete their projects and studies. Typically, only the datasheets provided by the modules' manufacturers are available. However, these datasheets describe the devices' electric properties under only one working condition, the standard test conditions (STCs). The main objective of this project is to present and validate an improved version of the previously developed and presented behavioural model (B-model) for photovoltaic modules [37]. The major advantages of this improved model are its simplicity and the fact that it is based only on the module's electrical properties available on the manufacturer's datasheet. The previous model was originally

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developed and validated using a rich experimental database only for polycrystalline silicon photovoltaic modules. Expanded validation tests are presented in this report using measured *I–V* characteristics for three other photovoltaic technologies: monocrystalline silicon, copper indium diselenide (CIS) and cadmium telluride (CdTe). To prove its efficiency, an example of its use is provided. Also, a detailed flowchart and description of its use are presented allowing a sound beginning for novices and newcomers in photovoltaic design/research.

The remainder of this paper is organised as follows: Section 2 addresses the model's fundamental principles, properties and mathematical expressions. Section 3 presents the model's improvements and instructions for use. Section 4 describes the database used which contains the measured *I–V* characteristics of three modules, monocrystalline silicon, CIS and CdTe, and presents the validation test using the measured database. Section 5 outlines a concrete example of the use of the B-model. Finally, Section 6 summarises the main results obtained and conclusions.

2. Presentation of the behavioural model

The B-model was first presented in [37]. It is a simple model for photovoltaic modules based only on the electric parameters provided by the manufacturers and available on their datasheets. The relationship between voltage and current is based on the mathematical expression of the first order system step response. However, the improved model can simulate the output electric characteristics for PV modules under any working condition by choosing ambient temperature and solar irradiance values which are expressed in Eq. (1), with: *I* being the modules' current; V_{oc} the open circuit voltage; I_{sc} the short circuit current; τ the voltage constant which determines the *I–V* curve's evolution at and near its maximum power point [37]; and *V* being the operating voltage

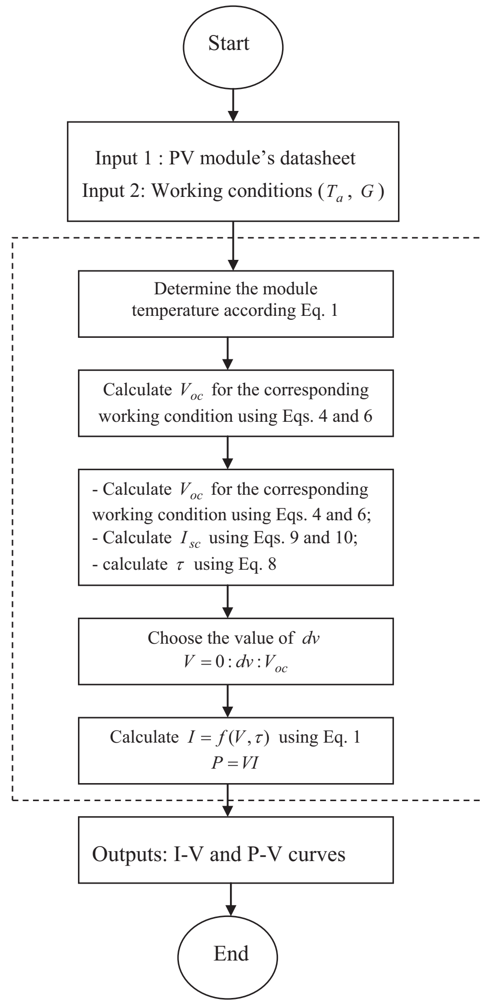

Fig. 2. B-model's instructions for use.

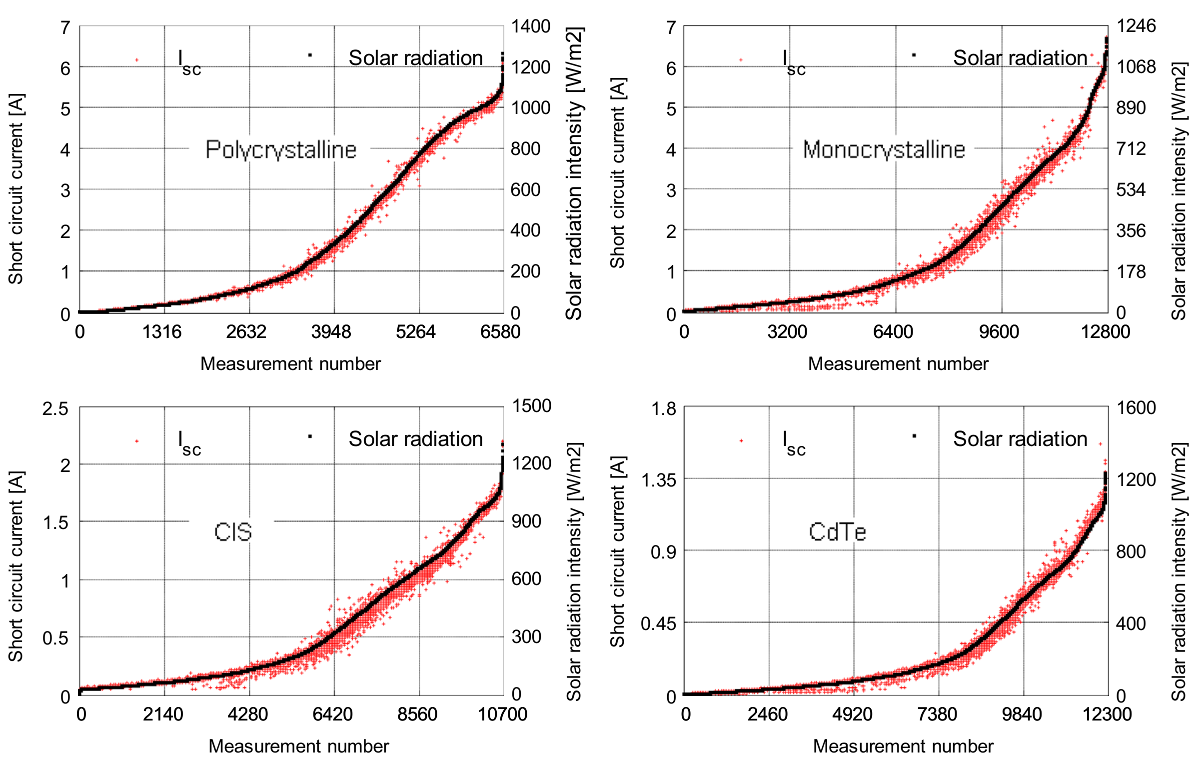

Fig. 1. The measured solar radiation intensity and the corresponding short circuit current [38].