International Journal of Energy Optimization and Engineering
Volume 11 • Issue 2

A New Reduced Form for Real-Time Identification of PV Panels Operating Under Arbitrary Conditions

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ABSTRACT

In this work, an efficient solution based on the reducing forms approach is presented to extract the five parameters of the single-diode model of PV generators from their I-V curves. Thus, by reducing the number of the five unknown parameters to two unknowns, the analytical expression of the current based on the LambertW function will then depend only on the ideality factor and the series resistance, as the two unknowns to predict numerically using the non-linear least square technique. The three other parameters are calculated as functions of the two predicted parameters using a linear system of three equations. Two sets of experiments are used for the validation of the proposed approach, which first showed its rapidity and high accuracy compared to the best approaches from the literature. Then, the method was applied for the real-time identification of four PV modules operating outdoors during one reference day at Cocoa (Florida).

KEYWORDS

Experimental Data, I-V Curve, Least Square Method, Modeling, Optimization Method, PV Characteristics, PV Technologies, Real-Time Values of the Five Parameters, Single Diode Model, Solar Cell

INTRODUCTION

Motivation

Given the great technological development of today, the energy needs of countries are also growing more and more. The massive consumption of fossil fuels such as oil, natural gas, bituminous rocks, and coal to produce the needed energy, led to the aggravation of the greenhouse effect by increasing the annual quantity of polluting gases emitted into the atmosphere (Geleta et al., 2019). It also implies the increase in the number of natural disasters and health diseases. Therefore, taking into consideration the natural, health, and economic problems facing the employment of fossil fuels' sources, besides their continuous reduction caused by their massive exploitation makes the production of energy a challenge of great importance (Kandiyoti et al., 2017; & Zaimi et al., 2018). Renewable energies such

DOI: 10.4018/IJEOE.309415
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as solar photovoltaic energy, wind energy, hydropower, biomass, and geothermal resources represent an alternative, sustainable, and ecological solutions (Yildiz., 2018; & Humada et al., 2016).

Solar energy is one of the most important renewable energies on which many countries rely as an alternative, it involves converting solar radiation into electricity using photovoltaic converters called cells which represent the basic element in photovoltaic conversion (Kharchenko., 2019;& Zhang et al., 2020). The association of multiple cells in series/parallel gives rise to a photovoltaic module. The identification of the parameters of PV modules or solar cells from their current-voltage experimental characteristics or using the datasheet is an active research topic. The parameters extraction is important for determining the PV generators' performances, simulating their design, and especially for their quality control and improvement (Ciulla et al., 2014). There are different circuit models which are used for modeling the behavior of PV generators. Due to its simplicity and efficacy, the single-diode equivalent circuit with five parameters (the light generated current or the photo-current I_{ph}, reverse saturation current I_s, diode ideality factor n, series parasitic resistance R_s, and shunt resistance R_p) is the most adopted model to describe the experimental current-voltage characteristics (Humada et al., 2016).

BACKGROUND AND LIMITATIONS

According to the literature, several methods have been proposed to extract the different parameters of the single-diode model with various degrees of accuracy and complexity. These methods can be classified into three approaches, namely analytical, numerical, and evolutionary approaches.

- Analytical approaches: These methods are simple, rapid, and use a series of analytical equations based on different remarkable points of the I-V curves (Saleem et al., 2009; Cubas et al., 2014; Louzazni et al., 2015; Maouhoub., 2017; & Batzelis., 2019). But most of these approaches rely on different approximations to reduce the non-linearity degree of the formulas.
- Numerical approaches: These methods either are based on the optimization process that minimizes the error between the theoretical I-V characteristic and the experimental curve (Bouzidi et al., 2007; Villalva et al., 2009; Yadir et al., 2009; Zhang et al., 2011; & Senturk et al., 2017), or the numerical resolution of a set of non-linear equations found using the values of the key-points (Kumar et al., 2017; Tifidat et al., 2021).
- Evolutionary approaches: These approaches are based on the meta-heuristic methods inspired from different natural phenomena. Then, they use various operations to ensure convergence such as crossover and mutation, techniques that can increase the needed calculation time (Awadallah., 2016; Maa et al., 2016; Xiong et al., 2018; & Sharma et al., 2021).
- Hybrid approaches: These kinds of methods are not based only on a single technique to extract the parameters, but they use a combination of more than one approach to identify the PV generator's parameters (Nassar-eddine et al., 2016; Abbassi et al., 2017).

Some of these methods are widely analyzed and reviewed in some review articles (Chin et al., 2015; Boutana et al., 2017; & Peñaranda Chenche et al., 2018).

Laudani et al (Laudani et al., 2013; & Laudani et al., 2014) suggested the extraction of the single-diode electronic circuit model's five parameters from current-voltage curves using the reduction of the search space. Indeed, this technique is based on reduced forms and decreases the dimension of the search space to two unknown parameters, then fitting the experimental I-V curve to get their values. The three other parameters are determined by using three analytical expressions based on preliminary selective data of the I-V curve; the open-circuit voltage (V_{oc}), the short circuit current (I_{sc}), and maximum power point MPP (V_{mp}, I_{mp}). Given that the values of the key-points available on the datasheet can be different from their real-values corresponding to the measured I-V characteristics,

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