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Parameter estimation of photovoltaic modules using iterative method and the Lambert W function: A comparative study

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ABSTRACT

This paper presents a comparative study of the parameter estimation methods which are based exclusively on the manufacturer's datasheets, for various technologies of photovoltaic (PV) modules, using the single diode five parameter model. Accurate determination of these parameters which arose from a diversification of models and methods dedicated to their estimations is still a challenge for researchers. In this study, two parameter estimation methods are employed: an iterative method which adjusts the series resistance and an analytical method based on the Lambert W function. These methods are used to calculate the five unknown parameters at Standard Test Conditions (STC) of three types of PV modules using different technologies, namely multicrystalline, monocrystalline, and thin-film. Five existing mathematical models are implemented to estimate the parameters of these PV modules under changing environmental conditions. These five models are classified from 1–5 for both parameter estimation methods. Each model is based on the combination of the reverse saturation current and the photocurrent. Then, the results of the different models simulations are compared with the measured data, which are extracted from datasheet characteristics in order to validate the reliability and evaluate the accuracy of the five models. The results of the implanted models indicate a high agreement between the measured data and the simulated *I–V* characteristics under varying temperature and irradiance. Moreover, the use of the Root Mean Square Error (RMSE) presents a good accuracy indicator for both methods. On the one hand, the results show that the combination of the analytical method of estimation with all five models guarantees the fewest errors between the estimated and measured data for the thin-film module under varying environmental conditions, especially at low temperature and high irradiance. On the other hand, the behavior of the two methods is almost the same for the monocrystalline and multicrystalline modules.

Contents

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Nomenclature

STC	Standard Test Conditions
I	the output current (A)
I_d	diode current (A)
I_{Rp}	parallel resistance current (A)
I_{PV}	photocurrent generated by the module (A)
I_{pvn}	photocurrent at STC (A)
I_S	diode reverse saturation current (A)
I_{Sn}	diode reverse saturation current at STC (A)
R_S	series resistance (Ω)
R_P	parallel resistance (Ω)
$R_{p,\min}$	minimum value of parallel resistance (Ω)
R_{P0}	value of R_P (Ω) at short circuit point (0, I_{SC})
A	diode ideality factor
N_S	number of cells in series
V	the output voltage (V)
V_t	thermal voltage (V)
V_{tn}	thermal voltage at STC (V)
K	Boltzmann's constant (=1.3806×10^{-23} J/K)
q	electron charge (=1.602×10^{-19} C)
T	temperature of the module (K)
T_n	temperature of the module at STC (=298 K)
G	irradiance of the module (W/m^2)
G_n	irradiance of the module at STC (W/m^2)
I_{sc}	short circuit current (A)
I_{scn}	short circuit current at STC (A)
V_{oc}	open circuit voltage (V)
V_{ocn}	open circuit voltage at STC (V)
V_{mpp}	maximum power voltage (V)
I_{mpp}	maximum power current (A)
$P_{\max,m}$	calculated value of maximum power (W)
$P_{\max,e}$	experimental value of maximum power (W)
K_I	current temperature coefficient (A/°C)
K_V	voltage temperature coefficient (V/°C)
E_g	band gap energy (eV)
dT	the temperature difference ($dT = T - T_n$) (K)

1. Introduction

Photovoltaic (PV) energy is currently experiencing strong growth worldwide. In Morocco, this development is boosted by a national policy that aims to reduce gas emissions by 13% by 2030 [1,2]. This reduction could reach 32% with enough international financial support [1,2]. Looking ahead, Morocco's national energy strategy is aiming to raise the share of renewable energy to 42% of the total installed capacity in the country by 2020, with solar, wind and hydro each contributing 14%. The country's ambitions grow in 2015 and Morocco is now determined to achieve a 52% share of renewables electricity generation capacity by 2030 according to the Moroccan announcement at COP21 (Conference of Parties) [1]. PV energy has become a way of producing electricity in addition to hydro and wind power In 2012, Morocco had a total capacity of 14 MWc divided between stand-alone PV systems (approximately 12 MWc) and grid-connected PV sites (approximately 2 MWc) installed as part of several programs such as PERG (Global Rural Electrification Program) and CHOUROUK program during the 2000s [2]. To increase the security of electricity supply and the quality of service in isolated regions, several sites have recently been identified for the large-scale collection of solar power. The largest of these sites to be developed is Noor solar complex which will be the world's largest solar site with a total power of 580 MW [2]. The first part of the complex is the Noor I Concentrated Solar Power (CSP) plant in Ouarzazate with a total power of 160 MW [2]. In July 2015, Morocco implemented a program to build several PV plants, namely the Noor-Tafilalt, Noor-Atlas, and Noor-Argana projects with a total power of 400 MWc connected to the high voltage network (HV: 60 kV) [2]. The Moroccan electricity and water utility company ONEE has decided to raise the capacity of the forthcoming Noor-Argana photovoltaic tender to 200 MW from 125 MW, bringing the total capacity of its photovoltaic program to 500 MW by 2018 [2]. From a legal point of view and in its endeavor to face energy and environmental issues, Morocco decided in 2009 to give impetus to the development of renewable energies by enacting several laws [1,3]. The last one of them is the law 58–15 which modifies and complements the existing 13–09 law on renewable energy to introduce a net metering scheme for solar and wind power plants connected to the high-voltage grid, and later, those connected at the middle and low-voltage level as well [1]. Private investors in renewable power will be able to sell their surplus output to the grid, but no more than 20% of their annual production [1]. Investors in PV will also benefit from the opening of the low-voltage grid to renewable power installations. Another use of solar energy is Solar Water Heating (SWH), for which the technical feasibility in residential buildings was assessed by Allouhi et al. [4] under Moroccan climatic conditions. In order to perform annual simulations of the SWH system, six climatic zones were used according to the recent climatic zoning established by ADEREE (National Agency for the Development of Renewable Energy and Energy Efficiency). They found that most Moroccan cities have significant potential in implementing SWH systems, and that the use of Evacuated Tube Collectors (ETC) is preferable and more suitable than Flat Plat Collectors (FPC) from a technical point of view. Furthermore, solar energy is also present in another application where biomass energy is converted into solar fuel in solar pyrolysis process. In this context, Zeng et al. [5] used a Box–Behnken experimental design/design of experiments to optimize solar pyrolysis process to produce combustible gases from beech wood, and found that wood energy content is upgraded by solar pyrolysis. Energy efficiency is generally based on the optimization of energy consumption and emissions of greenhouse gases. In this context, several solutions have appeared such as smart grids and nZEB (nearly-Zero Energy Buildings). Najibi and Niknam [6] introduced a new model of PV array by simulating and testing it on one typical Micro-Grid to see its performance regarding optimal energy management of Micro-grids,