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Accurate parametrization and methodology for selection of pertinent single diode photovoltaic model with improved simulation efficiency

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ABSTRACT

An accurate model of photovoltaic (PV) panel is indispensable for simulations studies. In general, the PV circuit parameters for simulation studies are extracted from the manufacturer's data sheet under different environmental conditions. The PV characterizing equations are nonlinear and requires a more involved computation. This paper presents a fast convergent third order Newton-type method to solve such nonlinear equations and thereby, to accurately parameterize any of the possible PV circuit models. The applicability and suitability of the proposed method are demonstrated through modeling of multi and mono-crystalline PV cells. Further an algorithm to evaluate the efficacy of the available methods and the proposed method is presented. PV characteristics of the suitable circuit model at various levels of temperature and irradiation are also examined. Finally, the effectiveness of the developed method is comprehensively assessed through comparison with the most recent and available effective techniques by considering various performance indices based on current-voltage, power-voltage curves and experimental data is carried out.

1. Introduction

Recent developments in photovoltaics (PV) and adverse effect on environment due to fossile fuel burning have heightened the need for injecting the green power into the grid (Khan and Xiao, 2016). In general, it is imperative to carryout the modeling and simulation of such systems a priori its practical implementation. Further, mathematical modeling of PV employed for simulation studies should be precise and reliable in order to extract maximum available power under varying environmental conditions (Xiao et al., 2013; Huang et al., 2016; Dondi et al., 2008; Chatterjee et al., 2011). In practice, it is strenuous to identify suitable PV circuit model and parametrization, from datasheet parameters (DP) for simulation studies, since it deliberate only the electrical characteristics, which include open circuit voltage, maximum power point, and short circuit current of the PV panel. However, the DP being the fundamental reference for matching the actual and modeled PV characteristics, considerable effort has been made towards this challenge in various directions. The parameter extraction based modeling, i.e., single diode PV (SPV) and double diode PV (DPV) models are the only feasible way to simulate current-voltage ($I-V$) and power-voltage ($P-V$) curves.

The majority of the research till date has focused on adopting the simplified PV models rather than its accurate counterpart at the cost of reduced accuracy. On contrary, the DPV exhibits a greater degree of accuracy and requires a higher computational efforts (Villalva et al., 2009; Adamo et al., 2011; Attivissimo et al., 2012; Ortiz-Conde et al., 2012; Romero-Cadaval et al., 2013; Humada et al., 2016). The application of SPV for various power electronics based simulation studies is well-known as it provides a fair trade-off between the model simplicity and accuracy (Villalva et al., 2009; Sera et al., 2007; Carrero et al., 2007; Yazdani et al., 2011; Kadri et al., 2011). The attractive feature of SPV lies in the fact that, it can be parameterized without assuming any unknown parameters, it solely depends on DP (Dondi et al., 2008; Chatterjee et al., 2011; Sera et al., 2007; Yazdani et al., 2011; Senturk and Eke, 2017). Besides, a simplified look-up table model describing the approximate PV cell characteristics as presented in Ropp and Gonzalez (2009) fails in tracking the true maximum power point (MPP). The suitability of analytical/numerical techniques in computing the $I-V$ curve based PV parameter is detailed in Chan and Phang (1987), Jervase et al. (2001), De Blas et al. (2002), Lingyun et al. (2011), Dondi et al. (2008), Chatterjee et al. (2011), Adamo et al. (2011), Sera et al. (2007), Yazdani et al. (2011), Walker (2001), Kuo et al. (2001), Celik and Acikgoz (2007), Benavides and Chapman (2008), Xiao et al. (2006), Liu et al. (2010). However, these methods require the actual measured data points of the $I-V$ curve.

Furthermore, a five parameter model of SPV is investigated in

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Nomenclature

E	irradiation (W/m^2)
T	temperature (°C)

Constant parameters

q	electron charge (1.6×10^{-19} C)
K	Boltzman constant (1.38×10^{-23} J/K)

Parameters to be estimated

A	modified diode ideality factor
i_{ph}	photon current (A)
i_s	diode saturation current (A)
R_s	series resistance (Ω)
R_{sh}	shunt resistance (Ω)

Datasheet parameters of PV cell

V_{oc}	open-circuit voltage (V)
I_{sc}	short-circuit current (A)
V_m	maximum output voltage (V)
I_m	maximum output current (A)
P_m	maximum output power (W)
α_T	current temperature coefficient (%/K)
β_T	voltage temperature coefficient (%/K)
γ_T	voltage irradiance coefficient ($V{\cdot}m^2/W$)

PV circuit parameters

i_{pv}, v_{pv}	PV current (A) and voltage (V) respectively
I_{pv}, P_{pv}	estimated PV current (A) and power (W) respectively
$\widetilde{I}_{pv}$, $\widetilde{P}_{pv}$	experimental PV current (A) and power (W) respectively
$\widetilde{I}_m$, $\widetilde{V}_m$, $\widetilde{P}_m$	estimated PV current (A), voltage (V) and power (W) at MPP respectively
$i_{ph}(E, T)$, $i_s(E, T)$, $V_{oc}(E, T)$	irradiation and temperature dependent Photon current (A), Diode saturation current (A) and PV cell Open-circuit voltage (V) respectively

Villalva et al. (2009), Carrero et al. (2007), Soon and Low (2012), Ma et al. (2016) while their extraction is practically constraint. Lambert W function is a non-iterative method proposed to reduce the computation efforts (Cannizzaro et al., 2014a,b). Where as several methods to compute the unknown parameters of the five parameter model by assuming one variable as a priori is also observed (Huang et al., 2016). The accuracy and convergence of such iterative methods depend on the chosen initial values. In order to combat this, differential evolution, particle swarm optimization methods (Soon and Low, 2012; Qin and Kimball, 2011; Ishaque and Salam, 2011) and linear least square approach (Lim et al., 2015) is proposed. In light of these recent developments in PV parameterization, a considerable concern about the simplified single diode models is witnessed. One of the way is to eliminate either series, shunt resistance or both (Xiao et al., 2004, 2007; Kuo et al., 2001; Tan et al., 2004; Veerachary and Khas, 2006; Celik and Acikgoz, 2007; Benavides and Chapman, 2008). However, this approach fails to in operating at true MPP. Unlike equation based models, parameters of no physical meaning (shunt or series resistance might be negative) is often difficult to use in circuit based models (Villalva et al., 2009; Charles et al., 1985; Xiao et al., 2004; Xiao et al., 2007).

Recapitulating the afore-mentioned remarks, an attempt is made to develop a simple and fast convergent parametrizing method while achieving the desired accuracy of PV modeling for simulation studies. In this paper, Adomian decomposition method (ADM) based higher order Newton-type method is formulated to solve the nonlinear PV characterizing equations, thereby to compute the unknown parameters of SPV for minimizing the MPP deviation. ADM is well applicable for class of nonlinear equations and it gives precise analytical solution to the initial value assigning problems. The proposed method is capable to reduce the computational complexity with high accuracy. A systematic algorithm embodying proposed parameter extraction method to avoid the initial value problem is proposed. The suitability and applicability of the developed method is validated through performance indices benchmarking considering the DP and experimental data points of the $I-V$, $P-V$ curves.

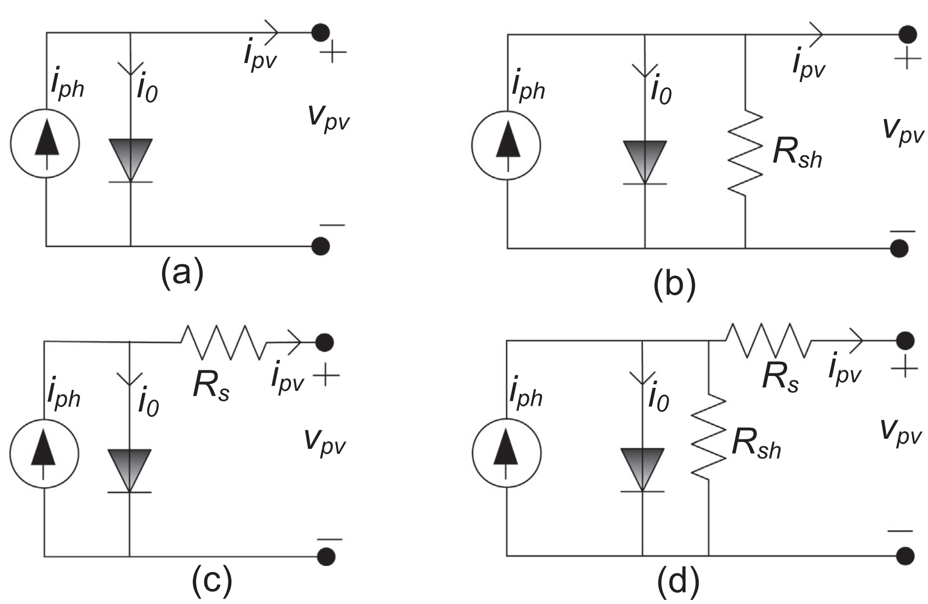

Fig. 1. Equivalent circuit of PV models (a) ISPV (b) ISPV-1 (c) ISPV-2 (d) CSPV.