Journal of Renewable Energies
Revue des Energies Renouvelables
journal home page : https://revue.cder.dz/index.php/rer

Research Paper

A summary of methods to get parameters values of photovoltaic cells/panels

Selma Tchoketch_Kebir [a,b,*]

[a] *Laboratoire de Dispositifs de Communications et de Conversion Photovoltaique, Electronic department, Ecole Nationale Polytechnique, 16 000 El-harrach, Algiers, Algeria*

[b] *Unité de Développement des Equipements Solaires, UDES/Centre de Développement des Energies Renouvelables, CDER, Bou-Ismail, 42415 W, Tipaza, Algeria*

ARTICLE INFO

Article history:
Received 14 August 2020
Accepted 04 October 2020

Keywords:
Photovoltaic
Modeling
I–V Curves
Manufacturer's Datasheet
Parameters' Determination
Identification,
Optimization

ABSTRACT

This paper presents a summary and comparative study of methods used for getting electrical unknown parameters of photovoltaic cells/panels. The exact parameters values are essential for precise mathematical modeling, simulation, and control of the photovoltaic generation systems. The many different methods are presented, discussed, and classified (general, analytical, numerical, optimization, adaptive). For comparison purposes, for each category of classification, a comparison among the best ones of them is done. An evaluation is elaborated based on the several chosen objectives function existing for the optimization-based approach. Besides, the performance of each used method is analyzed in relations of some norms: accuracy, ease of implementation, speed of convergence, computational complexity and quality of the obtained results. An effective evaluation under various climatic conditions, for diverse technologies materials, and for different manufacturers was discussed. Some statistical analysis is used to choose the best precise quality of the fitting curves to the real data. Some critical analysis is done with some evaluations, which serve to elaborate on this survey and synthesis study, which will be useful for researchers in the photovoltaic topic.

* *Corresponding author, E-mail address: selma.tchoketch_kebir@g.enp.edu.dz*

ISSN: 1112-2242 / EISSN: 2716-8247

1. Introduction

Economic crises, rising prices of fossil fuels, nuclear dangers, and climatic changes are nowadays the main reasons for choosing a mix energetic with renewable energies as a solution, among them, solar photovoltaic (PV) energy. As known, it can be applied in many applications such as PV autonomous plants as well as in PV grid-connected plants. The PV generator plays a major role and is considered as a crucial part of any PV plant. PV generator's performances are affected by many factors [1], where some of them are external, related to the environmental conditions like the weather's variations (irradiation and temperature), shading phenomenon [2], hotspot [3], dust, soiling [4], cell damage, and wind velocity. Others are internal, related to the electrical, physical and mathematical modelling [5]. Modelling is an important topic that necessitates the determination of the exact PV cell/panel's unknown parameters and thus optimizing the PV power generated [5]. After the modelling step of any PV generator, their identified parameters are used in the established model. With the problem of non-linearity found in PV models and the dependence of environmental conditions [6], the determination of PV parameters becomes a complex problem, which necessitates an appropriate approach to find the best accurate values of the unknown PV parameters. In this issue, many research topics have been developed for getting the PV parameters values [6-14]. The developed methods vary in terms of many aspects such as complexity, precision, convergence speed, popularity, robustness, and so on. For this reason, a different comparative study has been elaborated [6-16]. The comparison works developed before such as in [7] have presented an evaluation of three numerical methods. The work in [8] has evaluated metaheuristics based methods. The work in [9] has discussed a comparison of methods developed for obtaining the parasitic parameters (series and shunt resistances). In [10] a comparison work between single diode model (SDM) and double diode model (DDM) models. The work of [11] has presented an evaluation of different technologies such as organic and inorganic. Another work in [12] focuses on the dependence of weather conditions. The work in [13] deals with an overview of available approaches for PV parameters identification values. The evaluation was done between different models from the single diode model to the three diode model. Besides, it considers three kinds of PV technologies. In [14] different methods have been proposed to extract the PV parameters values, which are categorized in analytic, iterative, and evolutionary methods. The work of [15], presented several parameter extraction methods. These are reviewed in brief, followed by a proposition of a Newton-Raphson-based approach to parameter extraction of PV array. The work in [16] presents a critical evaluation of the parameters extraction of two diode

PV model using three evolutionary algorithm methods. Herein, the comparison was done by taking into consideration several PV technologies from several fabricants. This work summarizes the different comparative study done for PV parameters' getting values. It presents a latest classification of different types of methods (General, analytical, numerical, optimization, and adaptive). An evaluation and analyses work is elaborated between the different methods. Besides, it indicates the major different points to be considered in choosing an adequate method, such as the modelling, the objective function, the category of a method, some criteria, technology of PV material, various climatic conditions, and statistical analysis. The remaining of the paper is arranged as follow. Section 2 deals with the modeling process of PV cells and the formulation problem of obtaining PV parameters values. Section 3 presents the state of the art and classification of the major methods used for getting PV parameters values. In section 4, a focus is done in the comparison between the developed methods with consideration of some aspects. Section 5 gives some conclusions.

2. Modelling and problem review

In this section, details are provided about modelling, formulating the problem and the reasons for resolving it. There are several electrical models, used by researchers, describing the physical behaviours of PV cells. They are presented in Figure 1 [17, 18].

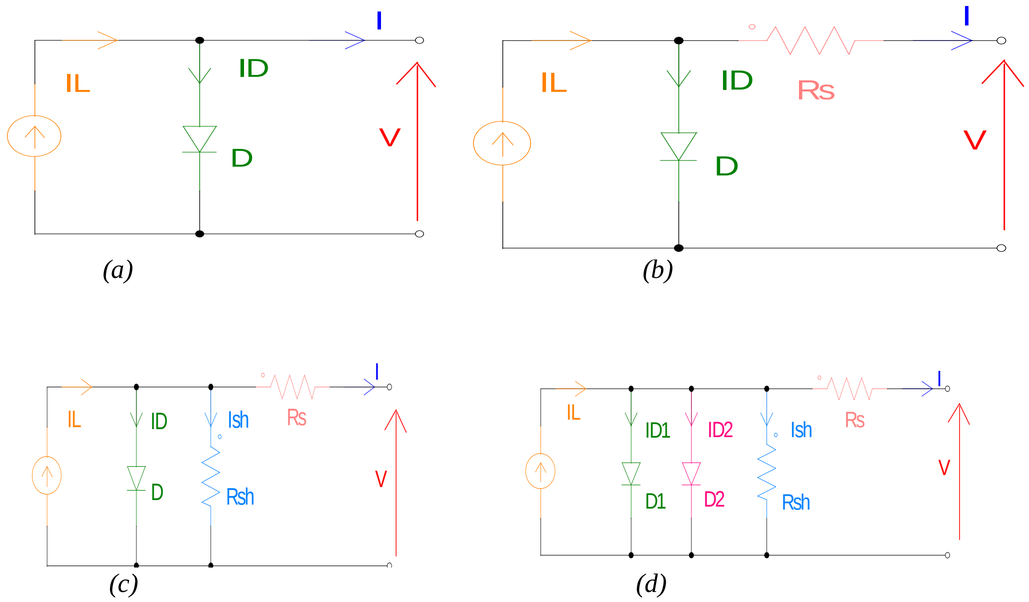


Fig 1. Electrical equivalent circuits of solar PV cells: *(a)* Ideal model. *(b)* Single diode model with series resistance. *(c)* Single diode model with series and shunt resistances. *(d)* Double diode model.

The equations of the different models of Figure 1 are given below.

❖ *First case « SDM: Single Diode Model »*

a) Ideal model (contains **three** unknown parameters)

$$I = I_L - I_D \quad (1)$$

$$I = I_L - I_{ds}\left(e^{\left(\frac{V}{n.V_t}\right)} - 1\right) \quad (2)$$

b) Single diode model with series resistance (contains **four** unknown parameters)

$$I = I_L - I_{ds}\left(e^{\left(\frac{V+R_s.I}{n.V_t}\right)} - 1\right) \quad (3)$$

c) Single diode model with series and shunt resistances (contains **five** unknown parameters)

$$I = I_L - I_D - I_{sh} \quad (4)$$

$$I = I_L - I_{ds}\left(e^{\left(\frac{V+R_s.I}{n.V_t}\right)} - 1\right) - \frac{V + R_s.I}{R_{sh}} \quad (5)$$

❖ *Second case « DDM: Double Diode Model »*

d) Double diode model (contains **seven** unknown parameters)

$$I = I_L - I_{D1} - I_{D2} - I_{sh} \quad (6)$$

$$I = I_L - I_{ds1}.(\exp(\frac{V + R_s.I}{n_1.V_t}) - 1) - I_{ds2}.(\exp(\frac{V + R_s.I}{n_2.V_t}) - 1) - \frac{V + R_s.I}{R_{sh}} \quad (7)$$

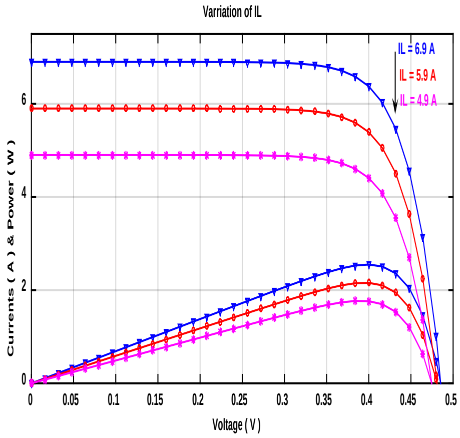
The overhead mathematical equations are in a non-linear form and have numerous unknown parameters. These latter are commonly undefined, not directly measurable, and not given from the fabricant manufacturers. These PV parameters are related to the physical behavior of cells, where.

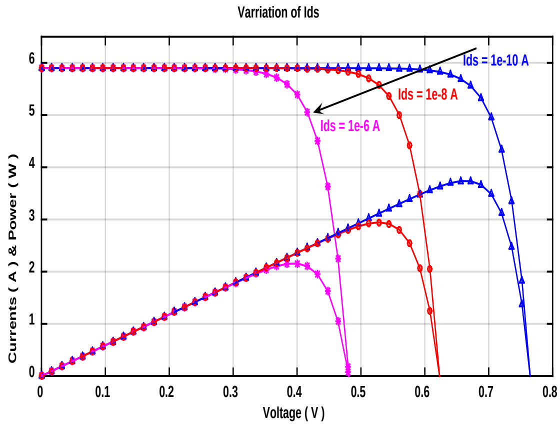
- I_L: Light current.
- I_{ds1}: Diode saturation current (*Diffusion phenomenon*).
- I_{ds2}: Reverse diode saturation current (*Recombination phenomenon*).
- n_1: Diode ideality factor (*Diffusion phenomenon*).
- n_2: Second diode ideality factor (*Recombination phenomenon*).
- R_s: Series resistance.

- R_{sh}: Shunt resistance.

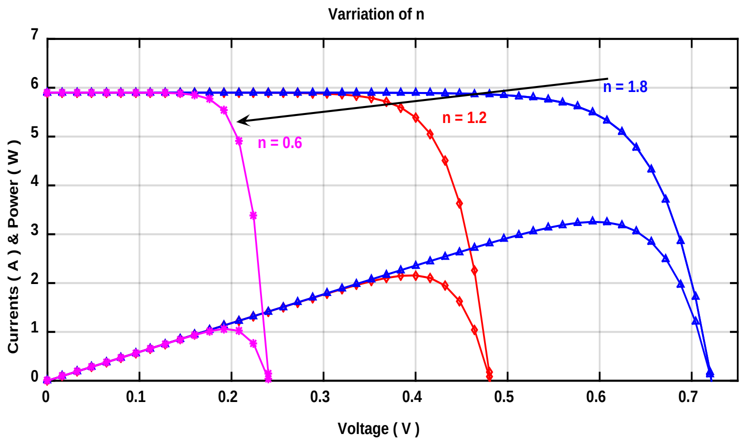
With $V_t = K_B * T_C$: Thermal voltage constant, K_B: Boltzmann's constant (1.380650*10 -23 J/K), q: Electronic charge (1.6021764*10-19 C) and T_C: Cell's temperature.

The overhead electrical governing equations contain several unknown parameters (I_L, I_{ds1}, I_{ds2}, n_1, n_2, R_s, R_{sh}). Each of the PV parameters has a crucial influence on the performances and PV power production. The effects of variation of the five PV electrical parameters on the solar photovoltaic cell's performances [19] are shown in Figure 2.

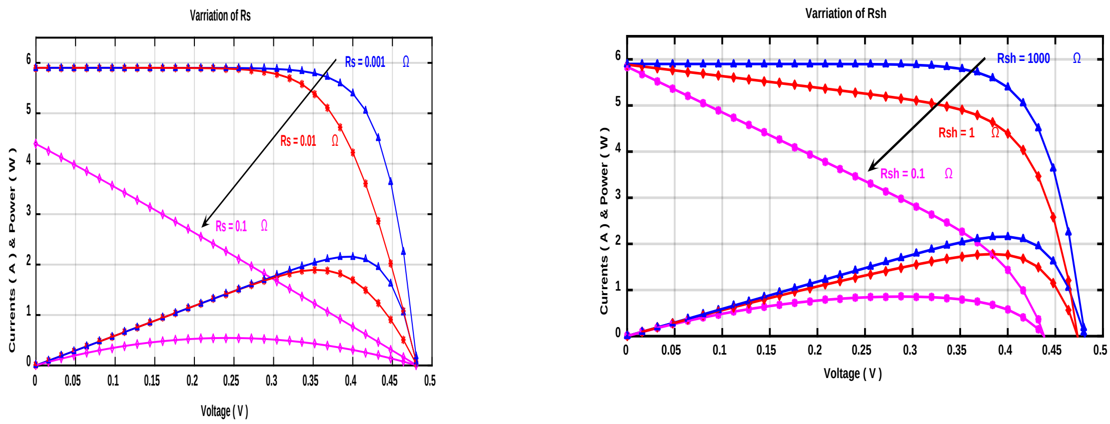




(a) *(b)*



(c)



(d) *(e)*

Fig 2. Variations effects of the electrical parameters on the (I-V) & (P-V) curves characteristics of solar PV cells: *(a)* Light current '$\mathbf{I_L}$'. *(b)* Diode saturation current '$\mathbf{I_{ds}}$'. *(c)* Diode ideality factor **'n'**. *(d)* Series resistance '$\mathbf{R_s}$'. *(e)*. Shunt resistance '$\mathbf{R_{sh}}$'

Figure 2. (a) illustrates the light current I_L effect, which is similar to that of the irradiation effect, so it has a proportional relationship with the generated current. Figure 2. (b), illustrates that diode saturation current I_{ds} has a proportional relationship with the voltage as shown, so it has an inverse effect compared to the temperature effect. In Figure 2. (c), the diode ideality factor n shows an effect on the obtained maximum power point (MPP). Figure 2. (d) and (e) illustrate that series R_s and shunt R_{sh} resistances have an effect on the slope at the open and short circuit points respectively. Consequently, each of these parameters has a crucial influence on the performances and the PV power production. This information involves the importance of accurate PV parameters values.

3. Classification of methods

Earliest, numerous research workings have been developed only for getting the series and shunt resistances values (parasitic effects), by the cause of their high influences in the PV performances [20]. Afterthought, it has been observed that some other electrical parameters (Light current, diode saturation current, and diode ideality factor) have also an effect in PV performances [19]. For this reason, researchers have done many works to get the electrical unknown PV parameters [5-15], [21] values with high precision and fast computational process. From the literature, these methods can be classified as the following Figure 3.

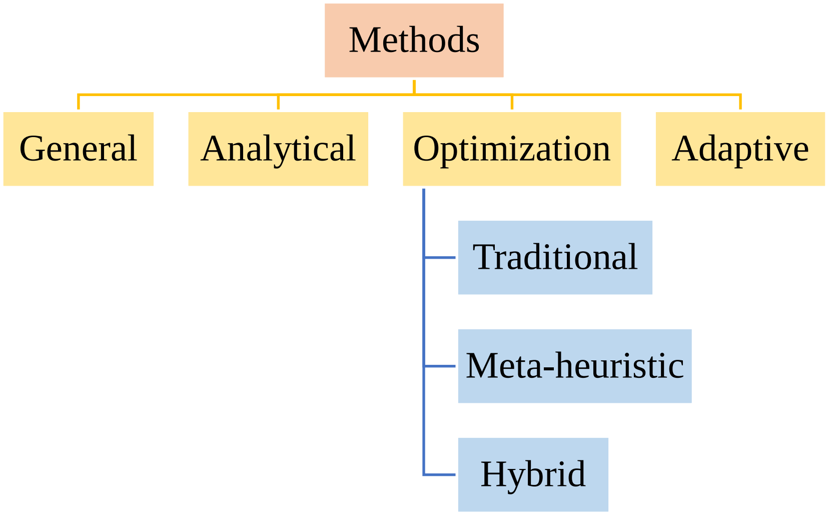


Fig 3. Classification of the PV panel's electrical parameters getting methods.

3.1 General methods

In a general way, *Duffie* obtained each parameter individually [22]. The parasitic resistances (series and shunt) are found graphically through the calculation of the slopes at open and short-circuits respectively [22, 23]. The diode ideality factor is taken in an interval depending on the used material's technology for the PV selected panels, for different manufacturers and different PV technologies (Si-Mono, Si-Poly, CDTE, Amorphous, CIS, Multi-junctions), as shown in Table 1 [23, 24]. Light current and diode saturation current are obtained by the use of mathematical expressions [21], and by the use of PV manufacturer's datasheet information.

Table 1. Diode ideality factor dependent on the PV material's technology.

Technology	Diode ideality factor
Si-Mono	1.2
Si-Poly	1.3
A-Si:H	1.8
A-Si:H tandem	3.3
A-Si:H triple	5
CDTE	1.5
CIS	1.8
AsGa	1.3

3.2 Analytical methods

Analytical methods such as *Carrero*'s method [25], are based on the analytical resolution of mathematical non-linear expressions through some simplifications and approximations [26], [27]. The use of explicit formulas such as in [28] leads to reasonable PV parameters values. The PV parameters can be found through an analytical way through the use of three points at the current-voltage (I-V) curve characteristic. These points are found at the short-circuit, open-circuit, and maximum power points (MPP) [28]. This lead to obtaining a set of expressions at each point. Then, through a suitable estimation to the problem, the problem can be approximated to a series of decoupled equations representing each parameter's value. This approach requires the datasheet information.

3.3 Optimization methods

The optimization algorithms are categorized into numeric- traditional, metaheuristics, and hybrid methods.

3.3.1 Numeric traditional

Numeric traditional optimization-based methods for PV parameters getting values, such as *Kashif*'s one [29], are based on the reduction of the number of parameters to be evaluated. The traditional Newton-Raphson (NR) method can also be used as developed in [30, 31]. It necessitates an iterative process with good initialization guess of PV parameters values, to converge to the best solutions. Besides, the traditional methods are used to obtain the optimum of the function using the gradient or the hessian.

3.3.2 Metaheuristics

In recent times, meta-heuristic optimization-based methods, using Artificial-Intelligence (AI) inspired algorithms, have attracted the care of researchers to obtain with good precision, the unknown PV parameters values. The metaheuristic methods use evolution-based [16], physics-based [32], or immune-human-based [33] and swarm-based [34], algorithms in the search process, which are presented in the subsections below.

A) Evolution-based

Evolutionary Algorithm (EA) [16], Differential Evolutionary (DE) [35], Genetic Algorithms (GAs) [36], Pattern Search (PS) [37], Simulated Annealing (SA) [38], Repaired Adaptive Differential Evolution (Rcr-IJADE) [29].

B) Physics-based

Electromagnetic Field Optimization (EFO), Gravitational Search Algorithm (GSA), Electromagnetism-Like Algorithm (EMA), Weighted Superposition Attraction (WSA) [40].

C) Human-based

Harmony Search (HS) [41], Bacterial Foraging Algorithm (BFA) [42], Simplified Teaching-Learning-Based Optimization (STLBO) [43], Discrete Symbiosis Organism Search (DSOS) [44], Artificial Immune system (AIS) [45].

D) Swarm-based

The swarm-based, Particle Swarm Optimization (PSO) [46, 47], Bird Mating Optimization (BMO) [48], Artificial Bee Swarm Optimization (ABSO) [49]. Grey Wolf Optimizer (GWO) [50], Chaotic Whale Optimization Algorithm (CWOA) [51], Cat Swarm Optimization (CSO) [52], and Cluster Analysis (CA) [53].

The metaheuristics are more attractive than the traditional deterministic methods in terms of accuracy and robustness, by the cause of their good global research achieving. In addition, they do not require a gradient or differentiable of the objective function. Besides, the initial guess of parameters values is not a necessity but it necessitates the upper and lower limits of an interval of research.

3.3.3 Hybrid methods

To improve the effectiveness of methods, researchers have combined a mix between different simple methods such as (analytical and numerical, analytical and optimization, numerical and optimization, so on). Hybrid adaptive Nelder-Mead simplex algorithm based on eagle strategy (EHA-NMS) [54], Nelder-Mead and Modified Particle Swarm Optimization (NM-MPSO) [55], Artificial Bee Colony-Differential Evolution (ABC-DE) [56], Trust-Region Reflective deterministic algorithm with the Artificial Bee Colony (ABC-TRR) [56], Teaching–learning–based Artificial Bee Colony (TLABC) [56]. Those methods, which are called hybrid, have excellent performances because they restrict the universe in the search process without losing precision (without losing the optimum). They achieve the best results in less number of iterations compared to simple optimization-based methods.

3.4 Adaptive methods

As the physical behavior of solar PV cells/panels is influenced by environmental conditions. There are several other methods in literature capable of finding the parameters of a more general model, in which the physical parameters models change concerning with irradiance and temperature values. Those models and their respective methods are called adaptive models and methods [54, 55].

4. Comparison and discussions

In this work, evaluations of the PV parameters determination methods have been attempted based on features, like modelling, chosen objective function, types of method's categories, some criteria, the technology of the used composite material, various climatic conditions, and the used statistical analysis.

4.1 Comparison based on modelling

Different models exist to describe the real physical behaviour of PV cells, single diode model (SDM), double diode model (DDM), three diode model (TDM), and others [56]. It is noted that as the number of diodes increases as the efficiency increase. Moreover, the precision of the characteristics of the models is more improved, but mathematical expressions become more complex. The SDM offers a compromise, but then again it requires the resolution of some equations to obtain the initial guess of PV parameters values.

In the following tables, there is a presentation of the manufacturer‘s characteristics from a cell and a panel in Table 2 [46].

Table 2. Characteristic data from R.T.C. France solar cell and Photo watt PWP201 solar panel.

Characteristic data	RTC France cell	Photo watt PWP201
I_{sc} (A)	0.7603	1.0300
V_{oc} (V)	0.5728	16.778
V_{mpp} (V)	0.4507	12.649
I_{mpp} (A)	0.6894	0.9120
R_{sho} (Ω)	246.80	689.13
R_{so} (Ω)	0.0907	25193
T (K)	306.15	318.15
N	1	36

A presentation of obtained PV parameters values for cell and panel, for different equivalent circuit parameters, are in Table 3 and 4 respectively.

Table 3. Equivalent circuit parameters and normalized root mean square error (RMSE), concerning the R.T.C. France solar cell.

Parameters / Models	I_L(A)	I_{ds1}(A)	n_1	I_{ds2}(A)	n_2	R_s(Ω)	R_{sh}(Ω)	RMSE
1D	0.7603	1.12x10-5	1.9509	-	-	-	-	2.25x10-2
1D/1R	0.7603	2.07x10-6	1.6944	-	-	0.0233	-	6.84x10-3
1D/2R-1	0.7616	4.14x10-8	1.3	-	-	0.0481	28.931	5.95x10-3
1D/2R-2	0.7604	1.44x10-6	1.6478	-	-	0.0261	246.77	5.48x10-3
2D/2R	0.7604	1.54x10-9	1.1087	5.15x10-6	2.0	0.0450	246.76	2.50x10-3

Table 4. Equivalent circuit parameters and normalized root mean square error (RMSE), concerning the Photo watt PWP201 solar panel.

Parameters / Models	I_L(A)	I_{ds1}(A)	n_1	I_{ds2}(A)	n_2	R_s(Ω)	R_{sh}(Ω)	RMSE
1D	1.0300	1.55x10-4	1.9319	-	-	-	-	2.87x10-2
1D/1R	1.0300	1.80x10-5	1.5520	-	-	0.8884	-	6.70x10-3
1D/2R-1	1.0330	7.04x10-7	1.2*	-	-	1.4429	497.75	4.59x10-3
1D/2R-2	1.0319	2.04x10-6	1.2968	-	-	1.2829	687.85	2.31x10-3
2D/2R	1.0318	5.31x10-6	1.3882	-1.96x10-5	2.0	1.2004	687.93	2.04x10-3

From the above tables, the PV parameters to be determined are variables according to the model of the chosen cell:

- From three to seven in the SDM.
- From four to eight in the DDM.
- More than ten in the TDM.

The formulation of PV modelling depends on the number of used diodes to describe the physical behaviour of cells. For all of the models used, it is improved in [56] that the metaheuristics are the most applied and investigated compared to analytical and numerical.

4.2 Comparison based on the chosen objective function

The optimization-based methods depend on the objective function to be optimized [48]. Some works used to optimize the error in current-voltage (I-V) curve characteristics such as absolute error, quadratic error, and root mean squares (RMS). Other works used to optimize the error in power-voltage (P-V) curve characteristics such as absolute error, quadratic error, and RMS. Some methods used to optimize errors from all points from the datasheet or from real data curves. Other methods used to optimize an objective function based on special points from the curves such as short-circuit, open-circuit, maximum power point (MPP).

4.3 comparison based on types of method's categories*:*

A comparison among the best methods for each method's category, i.e. a comparison among, the best analytical method, the best numerical method, and the best optimization-based methods.

4.3.1 Comparison between analytical methods

The major analytical methods have a similar way of getting off the PV parameters expressions values and lead usually to similar results [25-27].

4.3.2 Comparison between optimization methods

a) Numeric traditional

A presentation of three numeric methods' obtained parameters values is in Table 5 [7].

Table 5. Extracted single-diode PV model parameters using three numerical algorithms.

Parameters / Models	T. Esram	Vilalva	Vika
I_L (A)	1.220	5.500	5.532
I_{ds} (mA)	1.6e-6	2.0e-08	2.0e-8
n	1.833	1.200	1.200
R_s (Ω)	0.164	0.372	0.370
R_{sh} (Ω)	461.962	200.602	169.789

b) Meta-heuristics

An evaluation of some metaheuristics methods for PV parameters getting values is carried out as in [8]. Table 6 bellow presents a comparison between different metaheuristics parameters getting methods for SDM.

Table 6. Comparison among different metaheuristics parameters getting methods for SDM.

Parameters / Models	GA	PS	SA	HS	ABSO
I_L (A)	0.7619	0.7167	0.7620	0.76070	0.7608
I_{ds} (mA)	0.8087	0.9980	0.4798	0.30495	0.3062
n	1.5751	1.6000	1.5172	1.47538	1.4758
R_s (Ω)	0.0299	0.0313	0.0345	0.0345	0.0366
R_{sh} (Ω)	42.3729	64.1026	43.103	43.1034	52.2903

The metaheuristic methods transformed the difficult model of PV parameters getting values into a simple non-linear optimization problem. In addition, they use inspired algorithms from artificial intelligence to finding their precise values, which professionalism more the process of research [8].

c) Comparison between hybrid methods

Therefore, an evaluation between the obtained PV parameters values from simple PSO and the hybrid particle swarm optimization combined with simulated annealing (HPSOSA) is presented in the following Table 7.

Table 7. Comparison between PV parameters results from PSO and HPSOSA.

Parameters / Models	PSO	HPSOA
I_L (A)	0.7619	0.7167
I_{ds} (mA)	0.8087	0.9980
n	1.5751	1.6000
R_s (Ω)	0.0299	0.0313
R_{sh} (Ω)	42.3729	64.1026

From the works in [57], it is proved that the HPSOA has better performances compared to simple PSO and has achieved the global optimum in all test runs.

4.4 Comparison based on some criteria

The following tables compare a large number of methods based on some criteria (speed of convergence, prior knowledge of parameters values, relative error, and dependence on data).

Table 8. Comparative table of PV parameters getting methods related to some criteria.

Criteria / Methods	Convergence Speed	Prior knowledge	Relative Error	Dependence on data
Analytic	Slow	No-need	-	Datasheet
Numeric	Medium	Initial-guess	Normal	Datasheet
Meta-heuristic	Fast	Interval	Small	Datasheet & real
Hybrid	So-fast	Interval	Very small	Datasheet & real
Adaptive	Fast	Interval	Small	Real

Table 9. Comparative table of getting PV parameters metaheuristic methods related to some criteria.

Criteria / Methods	Accuracy	Consistency of solution	Convergence Speed	Computational efficiency	Number of control parameters
GA	Low	Low	Very low	Very low	4
PSO	Medium	Medium	Low	High	4
B-DE	High	High	High	Very high	2
P-DE	Very-high	Very-high	Very high	Very high	2

Results demonstrate that the Genetic Algorithm (GA) is not well to be applied for PV parameters estimation values. Better results have been obtained by PSO. When DE has shown the best results.

4.5 Comparison based on materiel's technology

Effective evaluation for getting PV parameters values has been expected, with the current-voltage characteristic, for several technologies [13] (monocrystalline, polycrystalline, thin-film, etc.), as in the following Table 10.

Table 10. Comparative parameters result in three different technology material.

Methods / Parameters	Monocrystalline SM55	Polycrystalline RSM50	Thin film ST40
I_L (A)	3.4599	3.1013	2.6840
I_{ds} (mA)	4.08e-10	6.44e-7	1.32e-7
n	1.0255	1.5256	1.2888
R_s (Ω)	0.0138	0.0110	0.0306
R_{sh} (Ω)	9.2737	25.9257	7.5466

4.6 Comparison based on various climatic conditions

As the physical comportment of photovoltaic panels is influenced by real environmental conditions such as irradiance or temperature [12], it is vital to find PV parameters values under variations of solar irradiance and environmental temperature, as in the following tables [13].

Table 11. Comparative table of getting PV parameters values under different irradiance conditions for the SM55 PV panel.

Methods / Parameters	G=1000	G=800	G=600	G=400	G=200
I_L (A)	3.4599	2.7655	2.0761	1.3870	0.6969
I_{ds} (mA)	4.0860e-10	1.0866e-8	3.349e-10	2.9842e-10	1.6012e-8
n	1.0255	1.1961	1.0104	1.0000	1.2175
R_s (Ω)	0.0138	0.0125	0.0176	0.0214	0.0122
R_{sh} (Ω)	9.2737	11.7863	10.7546	10.9664	11.3203

Table 12. Comparative table of getting PV parameters values under different climatic conditions for two panels connected in series.

Methods / Parameters	G=829.78 T=52.4	G=675.41 T=48.7	G=494.01 T=41.7	G=293.31 T=34.2
I_L (A)	3.997313	3.200398	2.101931	0.78870
I_{ds} (A)	2.53178e-2	1.3625e-5	1.5545e-8	1.1731e-13
n	287.98	283.3237	189.494	119.706
R_s (Ω)	0.052209	0.052066	0.010098	0.002321
R_{sh} (Ω)	7039.5730	1427.51	1039.3472	1518.4492

4.7 Comparison based on used statistical analysis:

To compare the performance between different methods, the following statistical indicators of accuracy are used.

- Error (ε)

$$\varepsilon = I_{Cal}(i) - I_{Exp}(i) \tag{8}$$

- Mean Absolute Error (MAE)

$$MAE = \frac{1}{N}\sum_{i=1}^{N}\left|I_{Cal}(i) - I_{Exp}(i)\right| \tag{9}$$

- Root Mean Square Error (RMSE)

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(I_{Cal}(i) - I_{Exp}(i)\right)^2} \tag{10}$$

Where I_{exp} is the current from real experimental measurement and I_{Cal} is the current from calculated/simulated data, and N is the data number. Table 13 presents the results of some used statistical analyses obtained from some methods.

Table 13. Comparison between some PV parameters getting methods based on used statistical analysis.

Methods	Cubas	El_naggar	Cong & Cai
E	2.85e-3	2.84e-3	2.20e-3
MAE	NA	2.0284e-3	1.6709e-3
RMSE	NA	2.7e-3	2.4251e-3

It is clear that based on statistical analysis comparison, it can be determined which approach is the most appropriate, accurate, and effective in terms of precision.

5. Conclusions

Accurate parameters values of PV cells/panels are essential for researchers in the modelling and the development of good controlling techniques for Maximum Power Point Tracking (MPPT) based power electronic converters. In this paper, a classification and an effective comparative study of the major PV parameters obtaining methods (general, analytical, numerical, optimization, and adaptive) through different characteristics was done, in terms of different points of comparisons. Each point of the latter is important to be taken into consideration when choosing an approach to get the PV parameters values. After doing some critical analysis, we have seen that there is a compromise of some characteristics for obtaining high effectiveness and precision of PV parameters values. It is necessary that the method chosen to be applied should ensure simplicity, rapidity, popularity, robustness, and high accuracy.

6. References

[1] Hongmei Tian, Fernando Mancilla–David, Kevin Ellis, Eduard Muljadi, Peter Jenkins. A Detailed Performance Model for Photovoltaic Systems. NREL/JA-5500-54601. 2012.

[2] Riad Kadri, Horia Andrei, Jean-Paul Gaubert, Traian Ivanovici, Gérard Champenois, Paul Andrei. Modeling of the photovoltaic cell circuit parameters for optimum connection model and real-time emulator with partial shadow conditions. Energy 42 (2012) 57e67.

[3] Pierluigi Guerriero, Santolo Daliento. Toward a Hot Spot Free PV Module. IEEE JOURNAL OF PHOTOVOLTAICS. 2019.

[4] Merissa Coello and Liza Boyle. Simple Model For Predicting Time Series Soiling of Photovoltaic Panels. IEEE JOURNAL OF PHOTOVOLTAICS, 2019.

[5] Samkeliso Shongwe, Moin Hanif. Comparative Analysis of Different Single-Diode PV Modeling Methods. IEEE JOURNAL OF PHOTOVOLTAICS, 2015.

[6] Mohamed Saleem ABDUL KAREEM, Manimaran SARAVANAN. A new method for accurate estimation of PV module parameters and extraction of maximum power point under varying environmental conditions. TURKISH JOURNAL OF ELECTRICAL ENGINEERING & COMPUTER SCIENCES, 2016.

[7] Ayodele T.R, Ogunjuyigbe A.S.O, Ekoh E.E. Evaluation of numerical algorithms used in extracting the parameters of a single-diode photovoltaic model. Sustainable Energy Technologies and Assessments 13 (2016) 51–59.

[8] Dhanup S. Pillai, N. Rajasekar. Metaheuristic algorithms for PV parameter identification: A comprehensive review with an application to threshold setting for fault detection in PV systems. Renewable and Sustainable Energy Reviews. 2017.

[9] Pyscha D, Mettea A, Glunz S.W. A review and comparison of different methods to determine the series resistance of solar cells. Solar Energy Materials & Solar Cells 91 (2007) 1698–1706.

[10] Ali M. Humada, Mojgan Hojabri, Saad Mekhilef, Hussein M. Hamada. Solar cell parameters extraction based on single and double-diode models: A review. Renewable and Sustainable Energy Reviews 56(2016)494–509.

[11] Chegaar M, Nehaoua N, Bouhemadou A. Organic and inorganic solar cells parameters evaluation from single I–V plot. Energy Conversion and Management 49 (2008) 1376–1379.

[12] Erdem Cuce, Pinar Mert Cuce, Tulin Bali. An experimental analysis of illumination intensity and temperature dependency of photovoltaic cell parameters. Applied Energy 111 (2013) 374–382.

[13] Rabeh Abbassi, Abdelkader Abbassi, Mohamed Jemli, Souad Chebbia. Identification of unknown parameters of solar cell models: A comprehensive overview of available approaches. Renewable and Sustainable Energy Reviews 90 (2018) 453–474.

[14] Rituraj Tamrakar, Archana Gupta. A Review: extraction of solar cell modelling parameters. International journal of innovative research in electrical, electronics, instrumentation and control engineering Vol. 3, Issue 1, January 2015.

[15] Valerio Lo Brano, Giuseppina Ciulla. An efficient analytical approach for obtaining a five parameters model of photovoltaic modules using only reference data. Applied Energy 111 (2013) 894–903.

[16] Kashif Ishaque, Zainal Salam, Hamed Taheri, Amir Shamsudin. A critical evaluation of EA computational methods for Photovoltaic cell parameter extraction based on two diode model. Solar Energy Volume 85, Issue 9, September 2011, Pages 1768-1779.

[17] Izadian A, Pourtaherian A, and Motahari S. Basic Model and Governing Equation of Solar Cells used in Power and Control Applications. 978-1-4673-0803-8/12 ©2012 IEEE.

[18] Hongmei Tian, Fernando Mancilla-David, Kevin Ellis, Eduard Muljadi, Peter Jenkins. A cell-to-module-to-array detailed model for photovoltaic panels. Solar Energy 86 (2012) 2695–2706.

[19] Kenneth, L. Kennerud. Analysis of Performance Degradation in CdS Solar Cells. IEEE Transactions on aerospace and electronic systems. VOL. AES-5, NO. 6. NOVEMBER 1969.

[20] Bashahu J. M, Habyarimana A. Review and test of methods for determination of the solar cell series resistance. Pergamon, Renewable Energy, 1995.

[21] Selma. Tchoketch Kebir, M. Haddadi, M. S. Ait-Cheikh. An Overview of Solar Cells Parameters Extraction Methods. IEEE proceedings, 3rd International Conference on Control, Engineering & Information Technology CEIT'2015.

[22] John A. Duffie, William A. Beckman. Solar Engineering of Thermal Processes. Book, Second Edition, John Wiley & Sons, INC. Chap 23, June 1980. (P 777).

[23] Ghani F, Rosengarten G, Duke M, Carson J.K. The numerical calculation of single-diode solar-cell modelling parameters. Renewable Energy 72 (2014) 105-112.

[24] Huan-Liang T. Insolation-oriented model of photovoltaic module using Matlab/Simulink. Solar Energy 84 (2010) 1318–1326.

[25] Carrero C, Ramirez D, Rodriguez J. Platero C.A. Accurate and fast convergence method for parameter estimation of PV generators based on three main points of the I-V curve. Renewable Energy 36 (2011) 2972-2977.

[26] Aldo Orioli, Alessandra Di Gang. A procedure to calculate the five-parameter model of crystalline silicon photovoltaic modules on the basis of the tabular performance data. Applied Energy 102 (2013) 1160–1177.

[27] Fahmi F. Muhammad, Ali W. Karim Sangawi, Suhairul Hashim, S. K. Ghoshal, Isam K. Abdullah, Shilan S. Hameed. Simple and efficient estimation of photovoltaic cells and modules parameters using approximation and correction technique. PLoS ONE 14(5): e0216201. 2019.

[28] Maria Carmela Di Piazza, Massimiliano Luna, Giovanni Petrone, Giovanni Spagnuolo. Translation of the Single-Diode PV Model Parameters Identified by Using Explicit Formulas. IEEE Journal of Photovoltaics (Volume: 7, Issue: 4, July 2017).

[29] Kashif I, Zainal S, Hamed T. Simple, fast and accurate two-diode model for photovoltaic modules. Solar Energy Materials & Solar Cells 95 (2011) 586–594.

[30] Cabestany J, Castanier L. Evaluation of solar cell parameters by nonlinear algorithms. 1983 J. Phys. D: Appl. Phys. 16 2547.

[31] Easwarakhanthan T, Bottin J, Bouhouch I, Boutrit C. Nonlinear Minimization Algorithm for Determining the Solar Cell Parameters with Microcomputers. International Journal of Solar Energy, 1986.

[32] Rashedi E, Nezamabadi-Pour H, Saryazdi S, GSA: a gravitational search algorithm, Information sciences, vol. 179, pp. 2232-2248, 2009.

[33] Meng-Hui Chena, Pei-Chann Chang, Jheng-Long Wu. A population-based incremental learning approach with artificial immune system for network intrusion detection. Engineering Applications of Artificial Intelligence (2016).

[34] Beni G, Wang J. Swarm intelligence in cellular robotic systems, in Robots and Biological Systems: Towards a New Bionics, ed: Springer, 1993, pp. 703-712.

[35] Kashif I, Zainal S. An improved modeling method to determine the model parameters of photovoltaic (PV) modules using differential evolution (DE). Solar Energy 85 (2011) 2349–2359.

[36] Zagroubaa M, Sellami A, Bouaicha M, Ksouri M. Identification of PV solar cells and modules parameters using the genetic algorithms : Application to maximum power extraction. Page 6. Solar Energy 84 (2010) 860–866.

[37] Al-Hajri M.F, El-Naggar K.M, AlRashidi M.R, Al-Othman A.K. Optimal extraction of solar cell parameters using pattern search. Renewable Energy 44 (2012) 238-245.

[38] El-Naggar K.M., M.R. AlRashidi, M.F. AlHajri, A.K. Al-Othman. Simulated Annealing algorithm for photovoltaic parameters identification. Solar Energy 86 (2012) 266–274.

[39] Wenyin Gong, Zhihua Cai. Parameter extraction of solar cell models using repaired adaptive differential evolution. Solar Energy 94 (2013) 209–220.

[40] Alkın Yurtkuran, İlker Küçükoğlu. “Comparative study of physics-inspired meta-heuristic algorithms for the solar cell parameter identification problem”. 16th International Conference on Clean Energy (ICCE-2018).

[41] Askarzadeh A, Rezazadeh A. Parameter identification for solar cell models using harmony search-based algorithms. Sol Energy 2012; 86:3241–9.

[42] N. Rajasekar Neeraja Krishna Kumar Rini Venugopala. “Bacterial Foraging Algorithm based solar PV parameter estimation”. Solar Energy. Volume 97, November 2013, Pages 255-265.

[43] Niu, Qun, Zhang, Hongyun, Li, Kang. ‘An improved TLBO with elite strategy for parameters identification of PEM fuel cell and solar cell models’. International Journal of Hydrogen Energy. 2014.

[44] Chaabane Bouali, Horst Schulte and Abdelkader Mami. “A High Performance Optimizing Method for Modeling Photovoltaic Cells and Modules Array Based on Discrete Symbiosis Organism Search”. Energies 2019, 12, 2246; doi:10.3390/en12122246.

[45] Basil Jacoba, Karthik Balasubramaniana, Sudhakar Babu Ta, S Mohammed Azharuddina, N Rajasekar. “Solar PV modelling and Parameter Extraction using Artificial Immune system”. Energy Procedia 75 (2015) 331 – 336.

[46] Hengsi Qin and Jonathan W. Kimball. Parameter Determination of Photovoltaic Cells from Field Testing Data using Particle Swarm Optimization. 978-1-4244-8052-4/11/$26.00 ©2011 IEEE.

[47] Jing Jun Soon, Kay-Soon Low. Photovoltaic Model Identification Using Particle Swarm Optimization with Inverse Barrier Constraint. IEEE Transactions on power electronics. 2012.

[48] Alireza Askarzadeh, Alireza Rezazadeh. Extraction of maximum power point in solar cells using bird mating optimizer-based parameters identification approach. Solar Energy 90 (2013) 123–133.

[49] Alireza Askarzadeh, Alireza Rezazadeh. Artificial bee swarm optimization algorithm for parameters identification of solar cell models. Applied Energy 102 (2013) 943–949.

[50] Darmansyah. Imam Robandi. "Photovoltaic Parameter Estimation Using Grey Wolf Optimization". 2017 3rd International Conference on Control, Automation and Robotics.

[51] Oliva D, Abd El Aziz M, Ella Hassanien A. Parameter estimation of photovoltaic cells using an improved chaotic whale optimization algorithm. Appl Energy 2017; 200:141–54.

[52] Guo L, Meng Z, Sun Y, Wang L. Parameter identification and sensitivity analysis of solar cell models with cat swarm optimization algorithm. Energy Convers Manage 2016; 108 : 520–8.

[53] Sandrolini L, Artioli M, Reggiani U. Numerical method for the extraction of photovoltaic module double-diode model parameters through cluster analysis. Applied Energy 87 (2010) 442–451.

[54] Chen Z, Wu L, Lin P, Wu Y, Cheng S. Parameters identification of photovoltaic models using hybrid adaptive Nelder-Mead simplex algorithm based on eagle strategy. Appl Energy 2016; 182:47–57.

[55] Hamid NFA, Rahim NA, Selvaraj J. Solar cell parameters identification using hybrid Nelder-Mead and modified particle swarm optimization. J Renew Sustain Energy 2016; 8:015502.

[56] Hachana O, Hemsas KE, Tina GM, Ventura C. Comparison of different metaheuristic algorithms for parameter identification of photovoltaic cell/module. J Renew Sustain Energy 2013;5.

[57] Muhammad Ali Mughal, Qishuang Ma, Chunyan Xiao. Photovoltaic Cell Parameter Estimation Using Hybrid Particle Swarm Optimization and Simulated Annealing. Energies 2017, 10, 1213; doi:10.3390/en10081213.