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Evolutionary Algorithms for Solar Photovoltaic Parameters Estimation - A Review

S. Senthilkumar[1], V. Mohan[2], G.Chitrakala[3]
[1]*Assistant Professor, Department of ECE*
[2]*Professor & Head, Department of EEE*
[3]*Associate Professor, Department of EEE*
[1,2,3] *E.G.S. Pillay Engineering College, Nagapattinam*

Abstract

Solar panels are an indispensable and main constituent for solar energy tapping as they are instrumental in conversion of solar radiation into electrical voltage equivalent. Optimal generation of power from these solar panels is a prime issue of research as it depends on several attributes mostly related to the sizing and modelling of photovoltaic (PV) panels for the required applications. In most cases, an array of solar cells is used for generation of small to medium scale power generation. Sizing of the panels, the storage process, utilization of electrical circuits in the process, are some essential research attributes which collectively determine and define maximum power generation from the solar panel. Parameter and circuit level modelling has been taken as prime issue of investigation and various state of the art techniques to determine the optimal sizing with respect to various circuit models such as single diode model (SDM) and double diode models (DDM) have been investigated in an extensive manner in this review article. It provides the concepts, features, and highlights the advantages and drawbacks of cell models. In this paper, we discuss the several algorithms and techniques used by both SDM and DDM and a deep study into the analysis of parameter estimations in each diode have been reviewed. Based on the conducted review, some recommendations for future research are provided.

Keywords: *Solar energy, Photovoltaic systems, parameter estimation, single diode and double diode models, Evolutionary algorithm.*

1. Introduction

With rapid depletion of fossil fuels alternately termed as non-renewable sources of energy like petroleum, oil etc., need for renewable sources for tapping energy is in high demand and has attracted widespread research in the past two decades. Well known renewable sources of energy include solar, wind, tidal energies out of which solar energy is much preferred due to its high insolation levels and abundance. This has motivated solar installations to be more dominant in the tropics characterized by high solar irradiations. Solar energy is one of the important renewable energy directly received from the sun for whole years and it is classified into two types. 1. Active solar – systems, solar water heater and concentrated solar systems. 2. Passive solar – Building orientation towards sun, suitable material selection and properties of light dispersion as well as the design of places in which air moves naturally [1]. Many countries rely on subsidies to promote the use of renewable energy technologies, such as wind energy and solar PV systems. Solar PV technologies should lower the cost of building solar PV modules in order to remain competitive [2]. There is a need for recommendations to minimize the CO_2 emissions using renewable energy. A system with embedded sustainability for categorization of parameters in the solar is clearly reviewed [3]. The basic block diagram of the PV system is shown in Figure 1.

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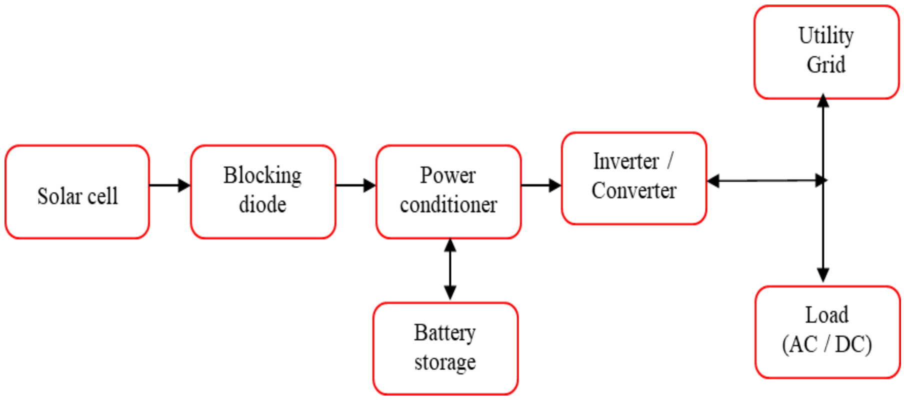

Figure 1. Basic Photovoltaic system

Modelling of cell has evolved over the years, with the focus on an analytical attitude based on easily available manufacturer data for the composite module. The alternative approach of relying on field measurement to underpin the development of a mathematical model for an array of interest has been largely unexplored. The results of an improved yet simple model can simulate and accurately predict the power output of an installed PV array in a given locality and for different climatic conditions [4]. The popular approaches employed for parameter estimations are Analytical techniques [5], Numerical extraction [6], and Evolutionary algorithm techniques [7]. The model of single- diode cell is the utmost commonly used model for modelling modules and arrays. It has five parameters to be extracted when modelling a system.

The ratio of current to voltage of the equivalent circuit model of a single-cell is determined by its explicit nonlinear transcendental equation, which is difficult to solve using analytical methods. Therefore, this method is not considered accurate. This difficulty led to the development of several algorithms for solving this equation using numerical methods. This is a potential tool for researchers and designers working in the field of PV systems to make decisions related to choosing the best possible algorithm for extracting the characteristic parameters of 5-parameter PV models with one diode [8]. But numerical methods have some drawbacks, such as premature integration, low accuracy, and instability. The application of curvature to the linear equation of a diode is completely different. However, the three-point method for extracting parameters for a single-diode model of the evolution algorithm uses only the rest of the curve for fine tuning. As a result, the complexity of the algorithm is significantly reduced and much more accurate than other documented methods [9]. It is believed that the methods of the evolutionary algorithm in are superior to the processing of nonlinear equations. Various optimization methods have been introduced to estimate solar parameters. This study aims to determine the optimization of cooling technology to increase the performance of the PV module [10].

Kok Soon Tey et al. [11] proposed a fast converging simple Maximum Power point Tracking (MPPT) technique with variations in irradiation of solar and load resistance (R_L) with reduced losses in generated power of cell. The algorithm proposed by them is much faster (4 times) when compared with conventional (incremental conductance) algorithm with respect to variations in solar irradiation and load. Himanshu Sekhar Sahu et al. [12] suggested an estimation technique for MPPT using Levenberg-Marquardt scheme under different conditions on environment for a DDM of a system and compare the obtained result with experimental data obtain from simulation in MATLAB and observed a better

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performance from the proposed technique. Utkarsh Jadli et al. [13] have modeled cell parameters to analyze the characteristic performance at different environmental conditions and observed that the characteristics of proposed model are very accurate when comparing with existing one.

2. Solar energy model

Solar models play a vital role in total energy production in the world and rapidly increasing day by day. On the other side, solar panel, batteries and inverters costs are decreasing significantly. Due to these reasons, many countries in the world are changing their energy policies towards solar systems.

Many research works are going in modeling of a solar cell. There are two main models of equivalent solar cell circuits,

1) Single-Diode Model (SDM)
2) Double-Diode Model (DDM)

2.1 Single-Diode Model

SDM is very simple to design and implement. Figure 2 shows the equivalent circuit of SDM. Here I_{ph}, I_{d1}, R_s, R_{sh} and n are the parameters to be estimated (Unknown parameters).

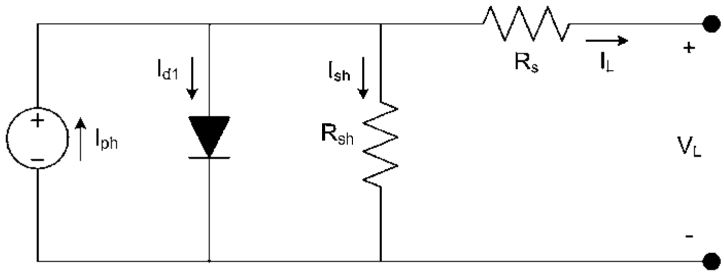

Figure 2. Equivalent circuit of Single-Diode Model

Figure 2 shows the SDM, it is mostly used for extracting I-V curve of solar cell. Output current of this SDM is given as

$$I_L = I_{ph-}\ I_0(\exp\left(\frac{V_L+I_L R_s}{aV_T}\right) - 1\Big) - (\frac{V_L+I_L R_s}{R_{sh}}) \qquad (1)$$

Where,

I_{ph} – Photogenerated current,
I_0 – Reverse saturation current of diode,
V_T – Thermal voltage ($V_T = K_T/q$),
K – Boltzman constant ($1.38065*10^{-23}$ J/K),
q – Electron charge ($1.60217*10^{-19}$ C),
T – Temperature in kelvin,
a – Diode ideality factor

The diode current of this model is given as follows

$$I_{d1} = I_0(\exp\left(\frac{V_L+I_L R_s}{aV_T}\right) - 1\Big) \qquad (2)$$

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The single diode equation assumes a constant value for the ideality factor n. In reality the ideality factor dominated by the surfaces and the bulk regions the ideality factor is close to one. Solar parameters for SDM are following,

Light induced current (I_{ph})

Light Beam Current induced is primarily a well-known method in the region for spatially resolved measurement of active recombination defects in prefabricated solar cells.

Diode dark saturation current (Is)

It's the current in a photodiode in the dark when you reverse-bias it, but not to the point of breakdown. You can see why that is from the equation for current through a photodiode in the dark.

Diode quality factor (m)

The ideological component of a diode used measure quality of a diode. The source of a simple diode equation uses some assumptions about the cell.

Series resistance (R_s)

The resistance of rear and top metal contacts. The key effect of Rs is reducing the fill factor, even though extremely great standards may reduce the short path current as well.

Shunt resistance (R_{sh})

Power losses caused by the presence of shunt resistance are usually associated with production defects and not poor solar cell design. Low shunt resistance causes loss of energy in solar cells, which provides an alternating current for the light generating current.

2.2 Double-diode model

Figure 3 shows equivalent circuit of DDM. Output current of this DDM is given as follows.

$$I_L = I_{ph} - I_{D1} - I_{D2} - I_{sh} \quad (3)$$

Where,

I_{D1} – First diode current
I_{D2} – Second diode current
I_{sh} – Current through shunt resistor R_{sh}

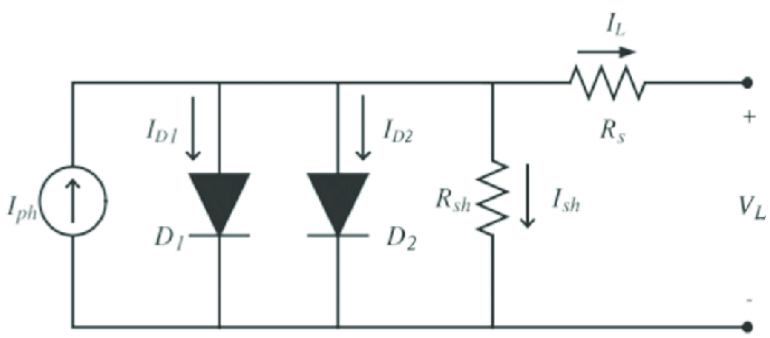

Figure 3. Equivalent circuit of double-diode model

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Current through diodes and shunt resistor are given by

$$I_{D1} = I_{01}(\exp\left(\frac{V_L + I_L R_s}{a_1 V_T}\right) - 1) \quad (4)$$

$$I_{D2} = I_{02}(\exp\left(\frac{V_L + I_L R_s}{a_2 V_T}\right) - 1) \quad (5)$$

$$I_{sh} = \left(\frac{V_L + I_L R_s}{R_{sh}}\right) \quad (6)$$

Where,

I_{01} – Reverse saturation current of diode 1.
I_{02} – Reverse saturation current of diode 2.
a_1 & a_2 - are diode ideality constants

Unlike the SDM, in the double-diode model, the effect of recombination current losses within depletion region is considered which leads to further improvement in the accuracy. Solar parameters for DDM are following,

- Light induced current (I_{ph})
- Diode dark saturation current (I_{01})
- Diode quality factor (a_1)
- Diode dark saturation current (I_{02})
- Diode quality factor (a_2)
- Series resistance (R_s)
- Shunt resistance (R_{sh})

Table 1. Comparison between SDM and DDM

Parameter	SDM	DDM
No. of parameters to be estimated	5	7
Components requirement	Less	More
Design	Simple and easy	Complex
Accuracy	Less than DDM	Better
Performance	Good	Superior than SFM

This study evaluates the comparison between SDM and DDM to improve the solar PV efficiency. Among the two models, design and implementation of first one is simple while the model with two diodes is more accurate, allowing a more accurate prediction of the performance of PV systems. One, a deterministic algorithm is used to estimate the parameters of two diode system, and the results are compared with the recently developed related work from different perspectives.

3. Evolutionary Algorithm

Different methods available for parameter estimation of solar cells are summarized in figure 4. Detailed literatures on different evolutionary algorithms are presented in this section

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3.1. Genetic Algorithm (GA)

J.D. Bastidas-Rodriguez et al. [14] have identified a SDM with five working points of generators running outdoor conditions using GA for different environmental conditions like solar irradiances and temperature and found that estimated parameters are very accurate when compared with other available estimating techniques. Joseph A Jervase et al. [15] have proposed GA to improve the already available cell parameter extraction techniques and obtain a result with error on the parameters extracted was ± 5% on the module values. Abdelghani Harrag et al. [16] have suggested a GA based solar parameter extraction method for five parameter and seven parameter model to improve the probability of finding global minimum with great accuracy in quick time. Here there is no restriction in solution space during the process [17].

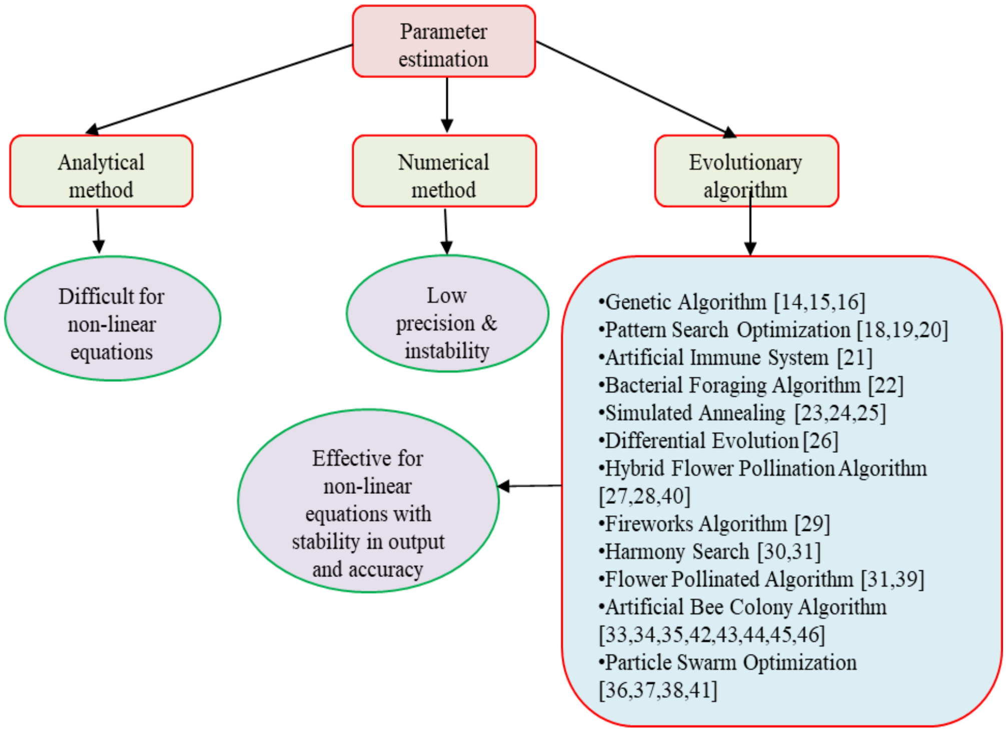

Figure 4. Different methods of solar parameter estimation

3.2. Pattern Search (PS) optimization

M. Derick et al. [18], proposed a PS algorithm to find solar cell parameter estimation of SDM through simulation and experimental method and investigate the effectiveness of PS algorithm for parameter estimation in MATLAB / Simulink under various environmental conditions like different temperature and solar irradiance and the results obtained in PS algorithm shows better in accuracy with short time of convergence. M.F.AlHajri et al. [19] have presented a parameter estimation of SDM and DDM solar systems using PS algorithm, PS algorithm accurately extract the parameter values of mentioned models. Amir Mohammad Beigi et al. [20] have estimated the solar cell parameters of SDM and DDM using PS algorithm, compared the estimated values with different available optimization algorithms and obtained results shows that PS algorithm is reasonable one for solar cell modeling.

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3.3. Artificial Immune System (AIS)

Basil Jacob et al. [21] have proposed an AIS algorithm to estimate the solar panel parameters for DDM, performance of AIS algorithm is compared with GA and PSO for different types of two modules and find that AIS performance overcomes GA and PSO algorithms with respect to convergence speed for two modules of.

3.4. Bacterial Foraging Algorithm (BFA)

N. Rajasekar et al. [22], proposed BFA for three different panels to model them accurately, observed better results like high precision, less convergence time, consistency and less error when compared with other optimization algorithm like GA and AIS.

3.5. Simulated Annealing (SA)

M.F. Brondani et al. [23], proposed SA algorithm for parameterization of battery model, obtained results have good battery lifetime and efficiency when compared with other optimization techniques. Ramzi Ben Messaoud [24] proposed SA algorithm which consists of three steps for extracting the parameters of SDM, first one is parameters extraction in conventional method, next one is parameters uncertainty determination and final one is instantaneous values of parameters determination, the proposed algorithm provides effective performance of the solar panel when compared with already existing technique. M.R. AlRashid et al. [25], presented SA algorithm for solar characteristics extraction and found that the proposed algorithm provides accurate parameter estimations.

3.6. Differential Evaluation (DE)

M.A. Abido et al. [26], estimated seven parameters of panel using DE algorithm, they considered six solar panels made up of mono crystalline silicon, poly crystalline silicon and thin film technologies. Extracted parameters values were compared with I-V curves of experimental data and found that proposed technique provides more accuracy on estimated parameters of panel.

3.7. Hybrid Flower Pollination Algorithm (HFPA)

J. Prasanth Ram et al. [27] proposed HFPA to solar parameter extractions for both SDM and DDM under various solar irradiance and temperature, proposed algorithm provide good parameter extractions with low Least Mean Square Error (RMSE) value under very lower values of solar irradiation. Shuhui Xu et al. [28] build a simple HFPA to estimating the solar parameters effectively and accurately for SDM and DDM and reported that the proposed algorithm provides superior results like accuracy, speed of convergence and stability of the model under different temperature and solar irradiations.

3.8. Fireworks Algorithm (FA)

T. Sudhakar Babu et al. [29], proposed a new FA for estimating the parameters of solar system, the proposed algorithm reduces premature in convergence probability and computational complexity and provide accuracy on estimated parameters near to the data sheet of the solar panel.

3.9. Harmony Search (HS) based algorithm

Alireza Askarzadeh et al. [30], proposed easy and better performing HS algorithm to extract the parameters of 57 mm diameter SDM and DDM solar cells made up of silicon, simulated in MATLAB Simulink, observed a lower RMSE value compared with PS and SA techniques and also difference between simulated values and values extracted experimentally from I-V curves are very small. Prachitara Satapathy et al. [31], HS based

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hybrid firefly algorithm for micro grid applications with quick convergence time and reduced randomization compared with FA and also observed that improvement in stability.

3.10. Flower Pollination Algorithm (FPA)

D.F. Alam et al. [32], proposed FPA for cell parameter extraction to achieve lower values on RMSE, quick finding of optimal solution and low convergence time under wide range of temperature and solar irradiations. Proposed FPA needs only a few control parameters.

3.11. Artificial Bee Colony (ABC) algorithm

Diego Oliva et al. [33], proposed ABC algorithm to extract the parameters of cell accurately; it was observed that ABC provides well search capacity for multi model objective functions and exhibits good performance on parameter estimation when compared with other available optimization algorithms like GA, HS, BFA and PSO. Mohammad Jamadi et al. [34], proposed an effective ABC algorithm to extract solar parameters for SDM and DDM models and found a fast and accuracy on parameters extraction compared with GA, PS, ABSO and PS techniques. Xu Chen et al. [35] proposed Hybrid Teaching Learning based Artificial Bee Colony (TLABC) for parameter extraction of different solar cells of SDM, DDM and solar modules; Obtained results when compared with other optimization techniques and found the proposed algorithm provides good accuracy and performance for estimation of different cell parameters.

3.12. Particle Swarm Optimization (PSO)

Meiying Ye et al. [36], applied PSO algorithm for solar cell parameter extraction and compare the result obtained from PSO algorithm with GA results for single diode and DDM and concluded that the proposed model obtain a high accuracy on estimated parameters with good computational efficiency. Nurul Farhana Abdul Hamid et al. [37] presented a PSO algorithm to extract the parameters of SDM with five parameters for a silicon solar cell of 57 mm diameter and verified the consistency of estimated parameters accuracy with other methods. Vandana Khanna et al. [38] estimated solar parameters for DDM using PSO and also calculated the cell voltage current (VI) characteristics.

Table 2. Comparison of different Evolutionary Algorithms

Algorithm	Merits	Demerits	Applications
GA	Better solution	Computation is complex Less accuracy	Effective method for parallelization, machine learning, robot path generation, analysis of DNA and data mining etc.,
PS	Better solution	Premature in convergence	Network security and information retrieval Computational molecular biology, spam filters, digital libraries and web search engine etc.,
AI	Search space is adjustable	Convergence speed is low	Pattern recognition, hand writing recognition, to diagnostic illness, Data analysis, optimization, machine learning, clustering, robotics and computer security etc.,

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BFA	Better solution, fast convergence	Computation is complex	Antenna array design, elimination of voltage harmonic on PWM inverter and distributed generation sizing
SA	Better solution	Temperature-Cooling schedule match is tough	Electric power systems, optimization problems, operational research and
DE	High accuracy	Difficult to find control parameter	Single function optimization, multi-function optimization, Classification of DNA, clustering, network training, data mining, power systems
HFPA	Convergence to global maximum and less RMSE	Low precision	Distributed systems, optimization of non-linear problems
FA	Efficient, robust, high accuracy	Consume more time	Information systems, data management systems
HS	Better solution	Convergence trajectory interrupts performance of the algorithm	Control systems, power systems, signal processing, image processing and information technology etc.,
FPA	Better solution	Convergence is delayed due to reduced fitness values	Distributed systems, optimization of non-linear problems
ABC	Better solution, fast convergence	Convergence failure in repeated progression	Cluster analysis, structural optimization, advisory system, bioinformatics and wireless sensor etc.,
PSO	Computations are fast	Difficulty in selection of initial parameter	Vehicle oscillations, provide global optimization solution for nonlinear problems

4. Scope for research

Some of the limitations of conventional electric power systems deploying large amounts of C, assessed the ability of the system to provide a significant share of a utility, production of a large hours actually used the system compares the quantity of electricity to be found, and this is the booking Indeed, infiltration levels and additional power system in the production of the current laws and rules of action. Low accuracy, high RMSE value and computation time are essential findings of this review. Comparing the effectiveness of a wide variety of meta-heuristics on the problem of estimating photocell parameters accuracy, consistency, and convergence rate, and determining the most appropriate meta-heuristics to solve this problem, will be an interesting and useful research network in the future. Apart from the issues discussed above, a few of problem statements that could be derived from study of literature are summarized below.

- ❖ A researcher may focus on maximum energy generation and full utilization of the generated energy by proper tapping of generated energy.

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- ❖ Efficient algorithm development for effective estimation of cell parameters in short period with high accuracy.
- ❖ A suitable optimization model has to be developed with admiration to different performance parameters which will improve the efficiency of the model.
- ❖ An effective MPPT technique has to be improved to track maximum power under different conditions like variations in temperature and irradiations.

Advantage of renewable energy systems could be summarized as follows

- ❖ Using appropriate conversion and precisely designed values for conversion stages, harmonic free generation of power could be achieved from RES in general.
- ❖ Renewable energy sources are non-polluting by nature as they do not emit any harmful or contaminating exit gases or smoke unlike conventional energy generation systems. The source of renewable energy is abundant in nature.
- ❖ Solar based power generation systems are also compatible with other renewable energy generation systems in the form of hybrid implementations which could help balance power shortages or outages during night times or seasonal weather variations.
- ❖ Finally, through a well-designed and laid out storage system, solar power generation could light up seasonal changes with respect to windy, rainy conditions and nightfall where solar radiations are minimal. In such cases, power from storage could be utilized in an intelligent manner.
- ❖ Optimal utility through efficient design and sizing of solar panels would ensure optimal power generation which may be fed to grids or micro-grids to power a small community.

5. Conclusion

Estimating parameters of PV cells is the main concern of today's researchers in renewable energy. A review of techniques for parameter estimation on both single and double diode has been carried out in this article by considering twelve kinds of algorithms. Also the performance and limitations of some recent existing methods are analyzed. This review paper will surely be very helpful for new researchers and for the researchers already working in this area in order to update their knowledge. As per our previous discussion, finally we will introduce a novel method to overcome the previous limitations and develop an enhanced applicable technique.

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