Aiding Prosumers by Solar Cell Parameter Optimization Using a Hybrid Technique for Achieving Near Realistic P-V Characteristics

Zain-ul-Abdin 1, Tahir Mahmood 1, Mohammad Shorfuzzaman 2, Neal Xiong3, and Raja Majid Mehmoond 4,*

1Department of Electrical Engineering, University of Engineering and Technology Taxila 47080, Pakistan
2Department of Computer Science, College of Computers and Information Technology Taif University, P.O. Box 11099, Taif 21944, Saudi Arabia.
3Department of Mathematics and Computer Science, Northeastern State University, 611 N. Grand Ave, #323, Webb center, Tahlequah, OK 74464.
4Information and Communication Technology Department, School of Electrical and Computer Engineering, Xiamen University Malaysia, Sepang 43900, Malaysia.

* Corresponding author: Raja Majid Mehmoond (rmeex07@ieee.org, rajamajid@xmu.edu.my)

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ABSTRACT The correct optimization of the solar cell electrical-model parameters is the key to produce better and more realistic P-V characteristics. This helps prosumers to select solar panels having better comparative efficiency, which in turn increases electricity production. Evolutionary Algorithms have shown comparatively good results in the estimation of these parameters. The Photon–current, Diode dark saturation current, Series resistance, Shunt resistance and Diode ideality factor, constitute the single diode’s unknown electrical model parameters. The mathematical-model of the P-V cell is derived in terms of Series-resistance and Diode-ideality factor. These two parameters are then used in a 2-variable single objective function. Using this derived model, Genetic Algorithm and Numerical method, a new parameter estimation technique has been proposed. Making use of machine learning and combination of two algorithms highlights the usefulness of the intended hybrid technique. P-V characteristic and relative maximum power point error of different solar cells, have been compared. The relative analysis disclosed that the proposed method offers more pragmatic P-V characteristics, as compared to the existing methods.

INDEX TERMS Genetic algorithm (GA), prosumers, maximum power point error (MPPE), Least Square Algorithm (LSA), parameter estimation (PE), meta-heuristic, solar photovoltaic (PV)

I. INTRODUCTION

To cope with the expanding requirements of electrical energy, solar photo-voltaic cells have gained a noteworthy research attention to amplify its application. Photovoltaic, being a part of Distributed Energy Resources (DERs) has made it possible for prosumers to take an active part in fulfilling energy demands. For the past decade, a great amount of research has been done in order to estimate unknown solar cell parameters accurately. To produce accurate P-V electrical model parameters, Analytical, Numerical and Meta-heuristic methods are usually opted. Analytical method [1], [2] is reliant on the right positioning of the data for the accurate estimation of solar cell parameters. So before the installation of the solar panel it is important to simulate the P-V characteristics to better optimize and control the PV systems. This data is acquired from the manufacturer’s data-sheet and Solar cell characteristic curve. Having number of attributes such as accuracy of results and less computational time makes these methods a good option but on the other hand, in case of large number of unknown parameters erroneous results should be expected [3]. Also higher computation is required in case of more variables. On contrary to the Analytical method, each sample points from the characteristic curve of the solar cell are considered, when using numerical methods. This provides more accurate results in comparison to the Analytical methods [3], [4]. So Numerical-methods such as Gauss Seidel [1], [7] and Newton-Raphson [5], [6] have often been used in researches for the estimation of solar cell parameters. Even though the degree of accuracy is high but the dependence of this method on accurate initial guess in case of more unknowns has been found difficult to predict [8], [9]. Because of this reason the solution can converge to a local-minima rather than a global- minima, in case of a
wrong initial guess. The use of machine learning algorithms is necessary to solve current day challenges related to optimization or other problems [26], [27], [28]. In order to sort out these certain problems in Numerical and Analytical techniques, several Meta-heuristic techniques were recommended which included Simulated-Annealing (SA) [13], Genetic-Algorithm (GA) [10], Particle-Swarm-Algorithm [11], [12], Teaching-Learning-Algorithm [15], Differential-Algorithm [14] etc. These methods proved to be more proficient in estimating the unknown parameters, as compared to the Numerical and Analytical techniques. But correspondingly these methods were slow in convergence and sometimes incapable of tracking actual characteristics [3], [4]. The contributions of this research are as follows:

- Computational efforts have been reduced in some of the research works by neglecting Shunt resistance “Rsh” [19], [20], Series Resistance “Rs” [17], [18] or by assuming the ideality factor “n” of the diode [3]. All these approaches lead to a less accurate estimation of MPPE [9], [21]. To increase the accuracy of results, this paper considers all five electrical model parameters.

- Furthermore, only two Parameters are estimated using Genetic Algorithm and the remaining 3 are evaluated using the least square method, which helps to reduce the computational efforts and increases precision of results.

- Resistance connected in series “rs” and the ideality factor (Modified) “Vdi” are two variables which are undetermined, so the derivation of the solar model is done accordingly. The derived model (objective function) has been applied to estimate the unknown “rs” and “Vdi “ using the Genetic Algorithm method.

- Using the least square method the parameters yet to be estimated namely Photon-Current (Iphn), Shunt-resistance (rsh) and Saturation-current (Id) are calculated.

- Finally, five different PV cells are considered to highlight the performance of the provided method. Performance Indices such as MPPE and P-V characteristic curve are compared with the existing and proposed method to reveal the accuracy of results.

The organization of the paper is as follows: Section II is about the solar cell optimization related work that has been published. Section III includes the derivation of the single diode mathematical model and the calculation of the objective function. Also discussion related to the estimation of parameters using Genetic and Least square algorithm will be presented in this section. In section IV, the proposed technique is applied on different solar panels to highlight its effectiveness. And comparison on the basis of Maximum Power Point Error (MPPE) has been devised. Section V provides with the concluding remarks.

II. Related Work

A good number of research papers have been published to determine the solar cell unknown parameters using a number of methods. These methods proved to be beneficial but each method had some setbacks associated with it.

A. Numerical Methods

These methods still have great demand for optimizing solar cell parameters. But still, for good results they are dependent on the accurate initial guess. In case of a wrong initial guess, the solution converges to local minima rather than global minima, which is considered as a setback. Gauss Seidel [1], [7] and Newton-Raphson [5], [6] methods are some of the examples of numerical methods.

B. Meta-Heuristic Methods

These methods are inspired by nature. Using these methods for optimization problems, help in more accurate estimations even with a slightly wrong initial guess these algorithms prove to be more accurate. The chances of the solution to converge at global optima are brighter. But still the number of iterations or the time consumed by the algorithm is comparatively more. Genetic-Algorithm (GA) [10], Particle-Swarm-Algorithm [11], [12], Simulated-Annealing (SA) [13], Teaching-Learning-Algorithm [15], Differential-Algorithm [14] are examples of meta-heuristic algorithms.

So it can be observed that each method has a certain liability associated with it. The proposed research offers a method, which uses both the numerical and Meta-heuristic algorithms in a hybrid manner to achieve better results.

III. Least Squares and GA based parameter determination and Mathematical Modeling

Because of simplicity and accuracy, single diode model is considered for estimation of parameters [22], [24]. Single diode model is depicted in Fig.1.
The resistance between the bulk material and metal contact is labeled ‘rs’, as shown in the Fig.1 and recombination of electron hole pairs is represented by ‘rsh’. The relationship between $I_0$ (Output Current) and $V_L$ (Voltage) in case of a single diode model is given in (1):

$$I_0 = I_{phn} - I_d \times \left[ \exp\left(\frac{V_L+I_0 \times rs}{Vdi}\right) - 1 \right] - \frac{V_L+I_0 \times rs}{rsh}$$  \hspace{1cm} (1)

Where,

$Vdi$= n.k.t.Scs/qe.

$n$=Ideality factor of the diode.

t=temperature (kelvins).

$k$=1.3806x10-23J/K (Boltzmann constant).

$q$=1.6021x10-19C (charge on an electron).

$I_d$ = Dark saturation current (Ampere).

$I_{phn}$ = Photon current (Ampere).

$Scs$= Number of series connected cells.

The remaining ‘$I_{phn}$’, ‘$I_d$’, ‘rs’, ‘rsh’ and ‘$Vdi$’ are yet to be determined as they have not been stated in the manufacturers datasheet. From (1) it is evident that the characteristic-curve is reliant on these undetermined parameters mentioned above. So in order to achieve results within close range to the real-characteristics, precise and accurate estimation of the above mentioned five unknown parameters is essential.

So (2), (3), (4), (7) and (9) are required for five unknown parameters, which are as follows:

I. By substituting $V_L=0$ in (1) and short circuiting the load terminal, $I_s$ (Short-Circuit Current) is obtained.

$$I_s = I_{phn} - I_d \times \left[ \exp\left(\frac{I_s \times rs}{Vdi}\right) - 1 \right] - \frac{I_s \times rs}{rsh}$$  \hspace{1cm} (2)

II. By substituting $I_0=0$ in (1) and placing an open circuit at the load terminal of the solar PV, following equation is obtained.

$$I_{phn} - I_d \times \left[ \exp\left(\frac{Voc}{Vdi}\right) - 1 \right] - \frac{Voc}{rsh} = 0$$  \hspace{1cm} (3)

III. By substituting ‘$vmp$’ and ‘$imp$’ in (1) (as vmp and imp are available in manufacturers datasheet)

$$imp = I_{phn} - I_d \times \left[ \exp\left(\frac{vmp+imp \times rs}{Vdi}\right) - 1 \right] - \frac{vmp+imp \times rs}{rsh}$$  \hspace{1cm} (4)

IV. The tangent drawn parallel to the voltage axis provides PV curve at mpp.

$$\frac{dp}{dv \_ mpp} = 0$$  \hspace{1cm} (5)

After solving (5) the equation becomes as follows

$$\frac{dI_0}{dV\_ mpp} = -\frac{imp}{vmp}$$  \hspace{1cm} (6)

The final Equation can be formulated by using (6) and (1)

$$imp = (vmp - imp \times rs) \times \left(\frac{I_d}{Vdi} \times \left[ \exp\left(\frac{vmp+imp \times rs}{Vdi}\right)\right] + \frac{1}{rsh}\right) = 0$$  \hspace{1cm} (7)

V. At short circuit, current is differentiated w.r.t to voltage which provides the slope.

$$\frac{dI_0}{dV_L} \_ is = \frac{1}{rsh}$$  \hspace{1cm} (8)

Solving (8) yields

$$\frac{I_d}{Vdi} \left[ \exp\left(\frac{ls \_ rs}{Vdi}\right)\right] \times (rsh - rs) = \frac{rs}{rsh}$$  \hspace{1cm} (9)

A. Derived Mathematical Model and Calculation of Objective Function

The parameters ‘rs’ and ‘$Vdi$’ are the two unknown parameters according to which the mathematical model or the characteristic equation of solar $P-V$ will be derived. After the derivation of the characteristic equation, GA has been applied to estimate the two unknown values. The convergence is faster and the results are accurate because the proposed characteristic equation has only two unknowns, rather than five.

The proposed characteristics equation derivation steps are as follows: To obtain the expression for ‘$Is$’ and ‘$imp$’, the value of ‘$I_{phn}$’ from (3) is substituted in (2) and (4).

$$Is = (y-x) \times I_d + \frac{Voc - Is \times rs}{rsh}$$  \hspace{1cm} (10)

$$imp = (y-z) \times Io + \frac{Voc - vmp - imp \times rs}{rsh}$$  \hspace{1cm} (11)

Where $x = \exp\left(\frac{voc \_ rs}{Vdi}\right) - 1, y = \exp\left(\frac{Voc}{Vdi}\right) - 1, z = \exp\left(\frac{vmp+imp \times rs}{Vdi}\right) - 1$

In order to find ‘$Is$’ and ‘$imp$’ in terms of ‘rs’, ‘rsh’ and ‘$Vdi$’, the value of ‘$I_0$’ from (9) is substituted in (7), (10) and (11) which yields:

$$Is = \frac{(y-x) \times Vdi \_ rs}{rsh \_ (1+x) \_ (rsh - rs)} + \frac{Voc - Is \_ rs}{rsh}$$  \hspace{1cm} (12)

$$imp = \frac{(y-z) \times Vdi \_ rs}{rsh \_ (1+x) \_ (rsh - rs)} + \frac{Voc - vmp - (imp \_ rs)}{rsh}$$  \hspace{1cm} (13)


imp = (vmp − imp × rs) \left( \frac{rs(1+z)}{rsh(1+z)(rsh-rs)} + \frac{1}{rsh} \right) \quad (14)

Furthermore, by equating (13) and (14) the value of ‘rsh’ is obtained as follows:

\[
\text{rsh} = rs + \frac{rs}{2vmp - Voc} \left( \text{vmp} - \text{imp} \right)^{Vdi(y-2)-(1+z)\text{imp}+rs)} \left( \frac{1}{x} \right) \quad (15)
\]

‘rsh’ can also be found by (12) and (13) as follows:

\[
\text{rsh} = \frac{\text{Voc}(x-z) + \text{Is} + \text{rs}(z-x) + (\text{vmp} + \text{imp} \times rs) \times (y-x)}{\text{Is}(z-x) + \text{imp}(x-y)} \quad (16)
\]

By using (15) and (16), the proposed equation can be derived as:

\[
f(rs, Vdi) = \left( \frac{rs}{2vmp - Voc} \right) \left( \frac{Vdi(y-2)-(1+z)(vmp - imp \times rs)}{1+x} \right) - \left( \frac{\text{Voc}(x-y) + Is + \text{rs}(z-x) + (vmp + imp \times rs)(y-x)}{Is(z-x) + imp(x-y)} \right) = 0 \quad (17)
\]

So the proposed equation (17) can only be used to find ‘rs’ and ‘Vdi’.

B. Extraction of Parameters Using Genetic Algorithm

From Charles Darwin’s theory of natural evolution a search heuristic named as Genetic Algorithm was inspired. In order to produce offspring of the next generation the fittest individuals are selected for reproduction, this process of natural selection is reflected in this algorithm.

In contrast with analytical methods, the genetic algorithm carefully evades the capture of the unknown parameters in the local-minima, which helps to achieve the global minima. To find the electrical model parameters of solar PV, the steps mentioned in the Fig.2 are followed [25]. In this research paper the Genetic algorithm has been used on 3 different mono and 2 poly-crystalline solar panels to demonstrate and compare the accuracy of this method. The combination of Genetic and Analytical algorithm helps to achieve desirable accurate results.

The results are far better than the parameters estimated by a single analytical technique for all five parameters. This reveals the competency of this hybrid algorithm. In this paper, Population Size, Number of Generations, Tour Size and Cross-over Probability are considered as 75, 95, 2 and 0.9 respectively for the GA based method.

C. Extraction of Parameters Using Least square Algorithm

IV. Results and Discussions

A. Attainment of P-V Characteristic-Curve using Proposed, Genetic and Least Square Method

Five different solar cells have been considered from [16] out of which three solar panels are mono-crystalline and the remaining two are polycrystalline. These solar cells are summarized in Table I.

Using the given parameters in the datasheet from Table I, estimation of parameters is carried out using all the above mentioned methods and a comparison is devised on the basis of accuracy with respect to the maximum power point in Table II (A, B, C, D, and E).

Using these results from Table II (A, B, C, D, E), the Power-Voltage characteristic curves have been obtained in Fig.3, Fig.4, Fig.5, Fig.6 and Fig.7. It is evident from the PV curve in Fig.3, Fig.4, Fig.5, Fig.6 and Fig.7 that the suggested approach is in close vicinity to the MPP (Maximum Power Point) as compared to the Genetic algorithm and Least Square Method. So considering the evaluation of five unknown parameters the proposed method highlights more realistic PV characteristics as compared to Genetic and Least Square method. So it can be said with certainty that more accurate results have been provided using the proposed approach.

\[
\text{fig 2}
\]
### TABLE I
Manufacturer’s Datasheet of Solar PV Panels

| Datasheet Parameters | JP-270-M60 (Nemy) (Mono) | STM-640-36 (Schutten Solar) (Mono) | TS-265-D60 (H-T GmbH) (Mono) | STP6-120-36 (Schutten Solar) (Poly) | SW-80RNA (Solar-world) (Poly) |
|----------------------|---------------------------|-----------------------------------|-----------------------------|----------------------------------|-----------------------------|
| vmp (V)              | 31.10                     | 16.98                             | 30.90                       | 14.93                            | 17.90                       |
| imp (A)              | 8.68                      | 1.50                              | 8.58                        | 6.83                             | 4.49                        |
| Voc (V)              | 38.60                     | 21.02                             | 38.10                       | 19.21                            | 21.90                       |
| Is (A)               | 9.20                      | 1.663                             | 9.19                        | 7.48                             | 4.78                        |
| Scs                  | 60                        | 36                                | 60                          | 36                               | 36                          |
| T (°C)               | 25                        | 51                                | 25                          | 55                               | 25                          |

### TABLE II (A)
Parameters determined using Least Square, Genetic and Proposed Method

| Name of the Solar Cell | Parameters to be Estimated | Least Square Method on 5 Equations | Genetic Algorithm | Proposed Technique |
|------------------------|-----------------------------|-----------------------------------|--------------------|--------------------|
|                        | Starting Point | Lower Bound | Upper Bound | Estimated Parameter | Lower Bound | Upper Bound | Estimated Parameters | Estimated Parameters |
| JP-270-M60 (Nemy) (Mono) | Iphn (A)       | 9.0         | 9.1        | 9.3                 | 9.1987      | --          | --          | 9.2003                     | 9.1974                     |
|                        | Id (A)          | 1e-7        | 1.0e9      | 1.2e-9              | 1.0259e-9   | --          | --          | 1.1940e-9                  | 1.0110e-9                  |
|                        | rs (Ω)          | 0.3         | 0.2        | 0.4                 | 0.3142      | 0.2         | 0.4        | 0.30985                    | 0.3043                     |
|                        | rsh (Ω)         | 9000        | 9100       | 9200                | 9100.1      | --          | --          | 9137.8                     | 9192.9                     |
|                        | Vdi             | 1.6         | 1.5        | 1.7                 | 1.6844      | 1.5         | 1.7        | 1.69706                    | 1.6840                     |

### TABLE II (B)
Parameters determined using Least Square, Genetic and Proposed Method

| Name of the Solar Cell | Parameters to be Estimated | Least Square Method on 5 Equations | Genetic Algorithm | Proposed Technique |
|------------------------|-----------------------------|-----------------------------------|--------------------|--------------------|
|                        | Starting Point | Lower Bound | Upper Bound | Estimated Parameter | Lower Bound | Upper Bound | Estimated Parameters | Estimated Parameters |
| STM-640-36 (Schutten Solar) (Mono) | Iphn (A)       | 1.6         | 1.5        | 1.7                 | 1.6634      | --          | --          | 1.6637                    | 1.6640                    |
|                        | Id (A)          | 1e-6        | 9.6e-7     | 9.9e-7              | 1.1225e-6   | --          | --          | 9.8541e-07                | 9.0122-07                |
|                        | rs (Ω)          | 0.2         | 0.2        | 0.3                 | 0.2704      | 0.2         | 0.3        | 0.23695                   | 0.2254                    |
|                        | rsh (Ω)         | 500         | 500        | 550                 | 504.234     | --          | --          | 502.9223                  | 486.2172                  |
|                        | Vdi             | 1.4         | 1.3        | 1.5                 | 1.4891      | 1.3         | 1.5        | 1.46780                   | 1.4582                    |

**FIGURE 3.** JP-270-M60 (Nemy) Mono P-V Curve

**FIGURE 4.** STM-640-36 (Schutten Solar) Mono P-V Curve
### TABLE II (C)
Parameters determined using Least Square, Genetic and Proposed Method

| Name of the Solar Cell | Parameters to be Estimated | Least Square Method on 5 Equations | Genetic Algorithm | Proposed Technique |
|------------------------|---------------------------|-----------------------------------|-----------------|-------------------|
|                        |                           | Starting Point | Lower Bound | Upper Bound | Estimated Parameter | Lower Bound | Upper Bound | Estimated Parameters | Estimated Parameters |
| TS-265-D60 (H-T GmbH)  |                          | 9.0            | 9.0         | 9.2        | 9.1909             | --          | --         | 9.1912           | 9.1911               |
| (Mono)                 |                          | 1e-7           | 5.7e-8      | 5.9e-8     | 6.2335e-8          | --          | --         | 6.1004e-08       | 6.3433e-08           |
|                        |                          | 0.1            | 0.1         | 0.2        | 0.1940             | 0.1         | 0.2        | 0.19412          | 0.19193              |
|                        |                          | 1000           | 1500        | 1700       | 1691.6             | --          | --         | 1676.2           | 1606.2               |
|                        |                          | 1.8            | 2.0         | 2.1        | 2.0197             | 2.0         | 2.1        | 2.01821          | 2.0269               |

### TABLE II (D)
Parameters determined using Least Square, Genetic and Proposed Method

| Name of the Solar Cell | Parameters to be Estimated | Least Square Method on 5 Equations | Genetic Algorithm | Proposed Technique |
|------------------------|---------------------------|-----------------------------------|-----------------|-------------------|
|                        |                           | Starting Point | Lower Bound | Upper Bound | Estimated Parameter | Lower Bound | Upper Bound | Estimated Parameters | Estimated Parameters |
| STP6-120-36 (Schutten Solar) (Poly) |                          | 7.4            | 7.3         | 7.5        | 7.4848             | --          | --         | 7.4848           | 7.4735               |
|                        |                          | 1e-6           | 8.7e-7      | 9.0e-7     | 9.4985e-7         | --          | --         | 9.3991e-07      | 1.0899e-06           |
|                        |                          | 0.1            | 0.1         | 0.2        | 0.1820             | 0.1         | 0.2        | 0.18168          | 0.19996              |
|                        |                          | 200            | 200         | 300        | 281.3830           | --          | --         | 282.0717         | 229.7820             |
|                        |                          | 1.3            | 1.1         | 1.3        | 1.2055             | 1.1         | 1.3        | 1.2066           | 1.2355               |

### FIGURE 5.
TS-265-D60 (H-T GmbH) Mono P-V Curve

### FIGURE 6.
STP6-120-36 (Schutten Solar) Poly P-V Curve

### TABLE II (E)
Parameters determined using Least Square, Genetic and Proposed Method

| Name of the Solar Cell | Parameters to be Estimated | Least Square Method on 5 Equations | Genetic Algorithm | Proposed Technique |
|------------------------|---------------------------|-----------------------------------|-----------------|-------------------|
|                        |                           | Starting Point | Lower Bound | Upper Bound | Estimated Parameter | Lower Bound | Upper Bound | Estimated Parameters | Estimated Parameters |
| SW-80RNA (Solar-world) (Poly) |                          | 4.7            | 4.6         | 4.8        | 4.7801             | --          | --         | 4.7801           | 4.7803               |
|                        |                          | 1e-7           | 6.7e-9      | 7.1e-9     | 6.9575e-9         | --          | --         | 6.9897e-09      | 6.8889e-09           |
|                        |                          | 0.2            | 0.1         | 0.3        | 0.2159             | 0.1         | 0.3        | 0.21553          | 0.2157               |
|                        |                          | 3000           | 3550        | 3650       | 3631.9             | --          | --         | 3600.9           | 3590.1               |
|                        |                          | 1.0            | 1.0         | 1.1        | 1.0747             | 1.0         | 1.1        | 1.07591          | 1.0756               |
V. Conclusions

At first the Characteristic equation of the Solar PV in terms of two unknowns, namely Series Resistance and Diode Ideality Factor has been derived in this paper. Furthermore the proposed characteristic equation is used in the Genetic algorithm to find the two unknowns ‘rs’ and ‘Vdi’. The remaining three parameters have been estimated using the Least Square Method. Five PV solar cells have been considered and compared to reveal the effectiveness of this approach. The PV curve and the MPPE have been estimated with the Least-square-method, Genetic algorithm and the proposed method. In comparison with the above mentioned methods, the proposed hybrid method highlights and offers PV characteristic curves closer to the real Characteristics. Also “rsh” and “rs” have not been neglected and ideality factor is also not assumed which has been done in previous works to reduce complexity but leads to less accurate estimations. Additionally, four equations instead of five equations for estimating five unknown parameters make the technique to be computationally less exhaustive. This will facilitate the prosumers in the acquirement of efficient solar panels thus increasing electricity generation.

B. Approximation of MPE of the PV Cell using Proposed, Genetic and Least Square Method.

The difference between the actual and the calculated power is known as relative error or maximum power error. This MPPE has been listed in Table III, which provides the values of actual power, calculated power and the error between them with respect to least, genetic and proposed algorithm.

It is evident from Table III that the proposed-method produces smaller values of MPPE in comparison to other methods with regard to the five solar panels mentioned in this study.

| Power (W) | Algorithms       | JP-270-M60 (Nemy) (Mono) | STM-640-36 (Schutten Solar) (Mono) | TS-265-D60 (H-T GmbH) (Mono) | STP6-120-36 (Schutten Solar) (Poly) | SW-80RNA (Solar-world) (Poly) |
|-----------|------------------|--------------------------|-----------------------------------|-----------------------------|----------------------------------|-------------------------------|
| Actual Max Power (PA) | Least-Square Method | 269.948                  | 25.47                             | 265.122                     | 101.9719                         | 80.371                        |
| Calculated Max Power (PC) | Genetic Algorithm | 269.4701                 | 25.4251                           | 264.0865                    | 101.4263                         | 80.2243                       |
| Error E=((PA-PC)/PA)*100% | Proposed Least-Square Method | 269.6605                 | 25.4391                           | 264.3775                    | 101.643                         | 80.3095                       |
|                          | Genetic Algorithm | 269.7208                 | 25.4585                           | 264.943                     | 101.8327                         | 80.3518                       |
|                          | Proposed         | 0.17703                  | 0.17628                           | 0.39057                     | 0.53504                          | 0.18252                       |

REFERENCES

[1] S. Shongwe and M. Hanif, “Comparative analysis of different single-diode PV modeling methods,” IEEE J. Photovolt., vol. 5, no. 3, pp. 938–946, May 2015.
[2] M. G. Villalva, J. R. Gazoli, and E. R. Filho, “Comprehensive approach to modeling and simulation of photovoltaic arrays,” IEEE Trans. Power Electron., vol. 24, no. 5, pp. 1198–1208, May 2009.
[3] J. Appelbaum and A. Peled, “Parameters extraction of solar cells – A comparative examination of three methods,” Sol. Energy Mater. Sol. Cells, vol. 122, pp. 164–173, Mar. 2014.
[4] T. T. Yetayew and T. R. Jyothsna, “Parameter extraction of photovoltaic modules using Newton Raphson and simulated annealing techniques,” in Proc. Power Commun. Inf. Technol. Conf., Oct. 2015, 1–6.
[5] A. Chatterjee, A. Keyhani, and D. Kapoor, “Identification of photovoltaic source models,” IEEE Trans. Energy Convers., vol. 24, no. 3, pp. 883–889, Sep. 2011.
[6] M. Uoya and H. Koizumi, “A calculation method of photovoltaic array’s operating point for MPPT evaluation based on one-dimensional Newton-Raphson method,” IEEE Trans. Ind. Appl., vol. 51, no. 1, pp. 567–575, Jan. 2015.
[7] S. Shongwe and M. Hanif, “Gauss-Seidel iteration based parameter estimation for a single diode model of a PV module,” in Proc. IEEE Elect. Power Energy Conf., Oct. 2015, pp. 278–284.
[8] J. Accarino, G. Petrone, C. A. Ramos-Paja, and G. Spagnuolo, “Sym-bolic algebra for the calculation of the series and parallel resistances in PV module model,” in Proc. Int. Conf. Clean Elect. Power, Jun. 2013,62–66.
[9] P-H. Huang, W. Xiao, J. C.-H. Peng, and J. L. Kirtley, “Comprehensive parameterization of solar cell: Improved accuracy with simulation efficiency,” IEEE Trans. Ind. Electron., vol. 63, no. 3, pp. 1549–1560, Mar. 2016.

[10] M. Zagrouba, A. Sellami, M. Boua’cha, and M. Ksouri, “Identification of PV solar cells and modules parameters using the genetic algorithms/caplication to maximum power extraction,” Sol. Energy, vol. 84, no. 5, pp. 860–866, May 2010.

[11] M. Ye, X. Wang, and Y. Xu, “Parameter extraction of solar cells using particle swarm optimization,” J. Appl. Phys., vol. 105, no. 9, pp. 1–9, May 2009.

[12] V. Khanna, B. Das, D. Bisht, and P. Singh, “A three diode model for industrial solar cells and estimation of solar cell parameters using PSO algorithm,” Renewable Energy, vol. 78, pp. 105–113, Feb. 2015.

[13] K. M. El-Naggar, M. R. AlRashidi, M. F. AlHajri, and A. K. Al-Othman, “Simulated annealing algorithm for photovoltaic parameters identification,” Sol. Energy, vol. 86, no. 1, pp. 266–274, Jan. 2012.

[14] L. L. Jiang, D. L. Maskell, and J. C. Patra, “Parameter estimation of solar cells and modules using an improved adaptive differential evolution algorithm,” Appl. Energy, vol. 112, pp. 185–193, Dec. 2013.

[15] S. J. Patel, A. K. Panchal, and V. Kheraj, “Extraction of solar cell parameters from a single current-voltage characteristic using teaching learning based optimization,” Appl. Energy, vol. 119, pp. 384–393, Apr. 2014.

[16] N. T. Tong and W. Pora, “A parameter extraction technique exploiting intrinsic properties of solar cells,” Appl. Energy, vol. 176, pp. 104–115, Aug. 2016.

[17] Y. T. Tan, D. S. Kirschen, and N. Jenkins, “A model of PV generation suitable for stability analysis,” IEEE Trans. Energy Convers., vol. 19, no. 4, pp. 748–755, Dec. 2004.

[18] N. D. Benavides and P. L. Chapman, “Modeling the effect of voltage ripple on the power output of photovoltaic modules,” IEEE Trans. Ind. Electron., vol. 55, no. 7, pp. 2638–2643, Jul. 2008.

[19] A. N. Celik and N. Acikgoz, “Modelling and experimental verification of the operating current of mono-crystalline photovoltaic modules using four and five-parameter models,” Appl. Energy, vol. 84, no. 1, pp. 1–15, Jan. 2007.

[20] M. Veerachary, “PSIM circuit-oriented simulator model for the nonlinear photovoltaic sources,” IEEE Trans. Aerosp. Electron. Syst., vol. 42, no. 2, pp. 735–740, Apr. 2006.

[21] P. Bhuradwaj, K. N. Chaudhury, and V. John, “Sequential optimization for pv panel parameter estimation,” IEEE J. Photovolt., vol. 6, no. 5, pp. 1206–1207, Sep. 2016.

[22] W. Xiao, F. F. Edwin, G. Spagnuolo, and J. Jatskevich, “Efficient ap-proaches for modeling and simulating photovoltaic power systems,” IEEE J. Photovolt., vol. 3, no. 1, pp. 500–508, Jan. 2013.

[23] O. Breitenstein, “An alternative one-diode model for illuminated solar cells,” IEEE J. Photovolt., vol. 4, no. 3, pp. 399–905, May 2014.

[24] E. A. Silva, F. Bradaschia, M. C. Cavalcanti, and A. J. Nascimento, “Parameter estimation method to improve the accuracy of photovoltaic electrical model,” IEEE J. Photovolt., vol. 6, no. 1, pp. 278–285, Jan. 2016.

[25] Haraag, A. Messali, S. Extraction of solar cell parameters using genetic algorithm 2015 4th International Conference on Electrical Engineering (ICEE), 2015, 1-5

[26] A. Shahzad, M. Lee, YK. Lee, S Kim, N. Xiong, JY. Choi, Y Cho, Real time MODBUS transmissions and cryptography security designs and enhancements of protocol sensitive information, Symmetry 7 (3), 1176-1210, 2015

[27] Q. Zhang, C. Zhou, N. Xiong, Y. Qin, X Li, S. Huang, Multimodel-based incident prediction and risk assessment in dynamic cybersecurity protection for industrial control systems, IEEE Transactions on Systems, Man, and Cybernetics: Systems 46 (10), 1429-1444, 2015.

[28] K. Huang, Q. Zhang, C. Zhou, N. Xiong, Y. Qin, An efficient intrusion detection approach for visual sensor networks based on traffic pattern learning, IEEE Transactions on Systems, Man, and Cybernetics: Systems, 47 (10), 2704-2713, 2017
the Best Paper Award in the 10th IEEE International Conference on High Performance Computing and Communications (HPCC-08) and the Best student Paper Award in the 28th North American Fuzzy Information Processing Society Annual Conference (NAFIPS2009).

Raja Majid Mehmood is an Assistant Professor in the School of Electrical and Computer Engineering, Information and Communication Technology Department, Xiamen University Malaysia, Sepang, Malaysia. Dr. Raja is IEEE Senior Member. He served as a research professor in the Department of Brain and Cognitive Engineering, Korea University. He was Lecturer in Software Engineering Department at King Saud University, Saudi Arabia. He obtained his Ph.D. in Computer Engineering from the Division of Computer Science and Engineering, Chonbuk National University, South Korea. He obtained his M.S. in Software Technology from Linnaeus University, Sweden. He received his B.S. in Computer Science from Gomal University, Pakistan. He has authored more than 50 research papers and is supervising or co-supervising several graduate (MS/PhD) students. His main research interests include affective computing, brain computer interfaces, information visualization, image processing, pattern recognition, multi-task scheduling, and software engineering.

Dr. Raja has served as a reviewer of various international journals including IEEE Communications Magazine, IEEE Transactions On Affective Computing, Int. J. of Information Technology and Decision Making, IEEE Access, Multimedia Tools and Applications, ACM Transactions on Multimedia Computing Communications and Applications, Journal of King Saud University - Computer and Information Sciences, Biomedical Engineering (BME), IEEE Internet of Things Journal, IEEE Transactions on Systems, Man and Cybernetics and so on.