# Fuzzy-Logic-based Approach for Organic Solar Cell Parameters Extraction

T. Bendib, F. Djeffal, D. Arar and M. Meguellati

***Abstract*—Extraction of the organic solar cell parameters is a complex task, because of the huge number of parameters in recent models; most of them correlated, and requires global optimization methods. The optimization methods are based on calculating derivatives and are thus quite computationally expensive and difficult to code. Therefore, in the present work, a new organic solar cell parameters extraction tool is presented. This tool is based on fuzzy control techniques. These techniques allow using knowledge about the model behavior into the parameter extraction method, thus simplifying the task. The procedure is applied to extract the different parameters of a single-diode solar cell model for which results show good performance. The obtained results make the proposed approach a promising candidate for organic solar cell investigations.**

***Index Terms*— Fuzzy computation, solar cells, Parameter extraction, I-V curves, modeling.**

## I. Introduction

In today's world, the importance of organic solar cells is rising in photovoltaic systems design. This is mainly due to the low manufacturing costs [1-5] because of the mass production of the organic solar cells by simple roll-to-roll or printing processes with lower thermal price and less stringent requirements than conventional inorganic semiconductor technology. The future of the organic solar cells will depend on improvement of their conversion efficiency. Compared to other inorganic counterparts, it shows low efficiency. Therefore, more study needs to be carried out on the organic solar cells, while keeping an eye on improving their conversion efficiencies. Accurate extraction and optimization of organic solar cell parameters are very important in improving the solar cell quality during fabrication process and in device simulation and modeling [3]. Extraction of the organic solar cell parameters is a complex task, because of the huge number of parameters in recent models. These parameters are, usually, the series resistances $R_s$, the shunt resistances $R_{sh}$, the cell-generated photocurrent $I_{ph}$, the diode saturation current $I_0$ and the diode ideality factor $n$ witch describe the nonlinear electrical model of the organic solar cell. Most of these parameters are correlated, and requires global extraction and optimization methods [6, 7]. One way to simplify this task is to use direct extraction methods for some parameters. This eases the entire extraction procedure and reduces the iteration time in case of optimization, because these values can be used as initial values. Once the parameters have been extracted, most of the direct extraction methods need a second step to take into account the interactions among the different parameters. This leads to the use of global methods (Genetic algorithms (GA), Particle Swarm Optimization (PSO), Multi-Objective-Genetic Algorithms (MOGAs), etc) to find the set of values that can best fit the experimental data [6,7]. The accuracy of these techniques is therefore limited by the high computational time caused by global optimization processing and the constraints functions used for parameter extraction. The other techniques for parameter extraction rely on the use of fitting algorithms to determine the solar cell parameters. Their accuracy depends on the applied fitting algorithm [6]. There are other methods such as finding parameters through complicated numerical analysis using Lambert's *W* function [8, 15]. However, these methods seem complicated processes for accurate extraction of parameters from a non linear solar cell characteristic. These models are obtained by simplifications of the full model of the organic solar cell which lead to the applicability limitations and a questionable accuracy. Therefore, the development of new approaches to overcome these limitations should be developed in order to study the solar cells for wide illumination range, where other parameters and double diode modeling should be taken into account.

In the present paper, we present an efficient technique for organic solar cells modeling, where simple and accurate solar cell parameters extraction method can be automatically achieved from a behavioral computational process to maximally reduce human trial and error efforts. In this context, in order to achieve the required accuracy and method simplicity, in this paper we present the applicability of Fuzzy Logic (FL) computation approach to extract the organic solar cell parameters. The correlation between the *I–V* curves drawn using final obtained parameter values and the measured *I–V* curves was demonstrated by the least-squares computation.

T. Bendib is with the Laboratory of Advanced Electronic, Department of Electronics, University of M'sila, 28000, Algeria (e-mail: bendib05.t@ gmail.com).

F. Djeffal is with the Laboratory of Advanced Electronic, Department of Electronics, LEPCM, University of Batna, 05000, Algeria (e-mail: faycaldzdz@ hotmail.com).

D. Arar is with the Laboratory of Advanced Electronic, Department of Electronics, University of Batna, 05000, Algeria (e-mail: d.arar@yahoo.com).

M. Meguellati is with the Laboratory of Advanced Electronic, Department of Electronics, University of Batna, 05000, Algeria (e-mail: m_meguellati@ yahoo.fr).

ISBN: 978-988-19252-8-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

## II. PROPOSED METHOD OF PARAMETER EXTRACTION

The simplified equivalent circuit of a one-diode model solar cell, may be described by the lumped parameter equivalent circuit of Fig. 1, which has been suggested in early 1980s [5].

For a given incident light intensity, at a given temperature, the implicit (I–V) analytical model is as follows:

$$I = I_{ph} - \frac{V + R_s I}{R_{sh}} - I_0\left[exp(\beta(V + R_s I)) - 1\right] \quad (1)$$

where $\beta = q / n_1 kT$ .

$I_{ph}$ represents the total current generated by the cell for a given lighting and temperature conditions in Amperes, k is the Boltzmann constant, q is the electron charge, T is the temperature, $R_s$ is the series resistance, $R_{sh}$ is the shunt resistance, $I_0$ represents the reverse saturation current; n is the diode ideality factor.

The processes associated with various compounds in the equivalent circuit of an organic solar cell are: The photo-current source generates current which is equal to number of dissociated excitons/s (number of free electron/hole pairs per second) [10]. The shunt resistance is due to recombination of charge carriers near the dissociation site (e.g. donor/acceptor interface) and it may also include recombination farther away from the dissociation site (e.g. near electrode). The series resistance reflects conductivity, i.e. mobility of specific charge carrier in the respective transport medium, where the mobility is affected by space charges and traps or other barriers (hopping) [10]. It is to note that the analysis of the processes associated with various elements of the equivalent circuit allows, to the designer, the control of each design parameter to develop the desired organic solar cell. The purpose of this work is to use the Fuzzy Logic (FL) technique to extract the parameters of organic solar cells. Furthermore, the method validation is done by calculating the errors in the curves obtained using the estimated parameters with respect to those curves obtained experimentally.

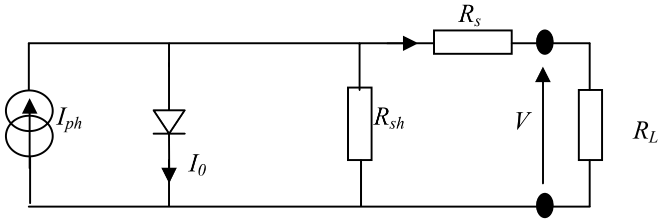


Fig. 1. Equivalent circuit of a single-diode model solar cell

The fuzzy logic provides an inference structure that enables appropriate human reasoning capabilities. On the contrary, the traditional binary set theory describes crisp events, events that either do or do not occur. It uses probability theory to explain if an event will occur, measuring the chance with which a given event is expected to occur [11]. Several published papers [11-13] offer extensive explanations to the fundamentals of FL and its wide range of applications. Due to its simple mechanism and high performance for behavior modeling, FL can be applied to study the I-V organic solar behavior in order to extract their electrical parameters, which is the main objective of this work.

To define the fuzzy associative memory, we need some knowledge about the how each of the electrical parameters affects the I-V curve behavior. I-V curves were drawn using MATLAB software. Changes in the shape of the I–V curve due to changes in parameter values were displayed in real time by the continuous execution of MATLAB program, allowing easy verification of visual effects of specific parameters on the shape of I–V curve. First, the shape of the I–V curve in the voltage region is depressed horizontally with a gradual increase in the value of $R_s$ from zero. When $R_{sh}$ decreases from infinity, the shape of the I–V curve in the current region is depressed leftward. The distinct change in the shape of the I–V curve due to changes in the ideality factor and reverse saturation current is that the open circuit voltage of the solar cell changes. Therefore, if parameters are extracted while assuming the ideality factor to be 1, there is significant error in the I–V curve drawn using the parameters [8].

As it is explained, previously, the I–V curve behavior will be used to define the fuzzy associative memory using some knowledge about the effect of each parameter on the I–V behavior:

- $R_s$ describes the curvature of I–V curve in the voltage region and shifts the short circuit current ( $I_{sc}$ ) value.

- $R_{sh}$ describes the curvature of I–V curve in the current region and shifts the open circuit voltage ( $V_{co}$ ) value.

- nand $I_0$ shift the open circuit voltage ( $V_{co}$ ) value.

Based on the effect of each parameter on the I–V curves, we can define the following rules in order to develop our knowledge Base for each parameter, which will be extracted:

- If the calculated I–V characteristic is more curved than the experimental data in the voltage region, then increase $R_s$ , and vice versa.
- If the calculated curve I–V is under the experimental data at $I_{sc}$ point, then decrement $R_s$ , and vice versa.
- If the calculated I–V characteristic is more curved than the experimental data in the current region, then increase $R_{sh}$ , and vice versa.
- If the calculated curve I–V is to the right of the experimental data in the voltage region, then decrement $R_{sh}$ , and vice versa.
- If the calculated curve I–V is to the right of the experimental data in the voltage region, then decrement n, and vice versa.
- If the calculated curve I–V is to the right of the experimental data in the voltage region, then increment $I_0$ , and vice versa.

It is to note that the curvature of the I–V characteristics for both regions, current and voltage regions, can be estimated from the computation of the slopes of the calculated I–V

ISBN: 978-988-19252-8-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

characteristic at the short circuit current point for the first region and at the open circuit voltage point for the second one.

In order to implement the above rules, we have used the triangular fuzzy sets, while defuzzification is done through the method of centre of area. The input and output parameters are normalized by using the experimental database as reference. The linguistic variables chosen for our FL-based approach is the mean square error (MSE) for each parameter of the I-V model. These errors are the input linguistic variables and the I-V model is the finale output linguistic variable. The error of each parameter represents the current deviation affected by the solar cell parameter, which will be extracted using the proposed approach. The fuzzy system is then expected to be able to reproduce the behavior of the experimental curves. Each of the input and output fuzzy variables is assigned seven linguistic fuzzy subsets varying from negative large (NL) to positive big (PL). Each subset is associated with a triangular membership function to form a set of seven membership functions for each fuzzy variable. The linguistic terms chosen for this controller are seven. They are negative large (NL), negative medium (NM), negative small (NS), zero (Z), positive small (PS), positive medium (PM) and positive large (PL). After assigning the input, output ranges to define fuzzy sets, mapping each of the possible four input fuzzy values of the calculated error with:

$$\Delta R_s = R_s - R_{s0} \quad (2a)$$

$$\Delta R_{sh} = R_{sh} - R_{sh0} \quad (2b)$$

$$\Delta V_{oc} = V_{oc} - V_{oc0} \quad (2c)$$

$$\Delta n = n - n_0 \quad (2d)$$

$$\Delta I_0 = I_0 - I_{00} \quad (2e)$$

$$\Delta S_1 = S_{1A} - S_{1E} \quad (2f)$$

$$\Delta S_2 = S_{2A} - S_{2E} \quad (2g)$$

$$\Delta I_{sc} = I_{sc} - I_{sc0} \quad (2h)$$

where $R_{s0}$, $R_{sh0}$, $V_{oc0}$, $n_0$, $I_{00}$ represent the slope of the experimental I–V curve at $V_{oc}$ point, the slope of the experimental I–V curve at $I_{sc}$ point, the experimental open circuit voltage, the experimental ideality factor and the experimental diode saturation current respectively.

## III. Results and discussion

The computation process will be carried out from an initial point, guest values, until a stopping condition is found (accuracy or iterations number). New parameter values, for each iteration, will be estimated by the fuzzy controller. The global RMS (Root Mean Square) error between the experimental and the calculated results, considering all points on the database, will be updated. The stopping condition used in our approach is the global RMS error. This latter should be less than 5%. The values for initialization of the FL-based computation approach for the investigated solar cell are: $[R_s, R_{ch}, n, I_0] = [2,50,1,10^{-11}]$. Fig. 2 shows good agreement between experimental and predicted results of the I-V characteristic for the investigated organ solar cell.

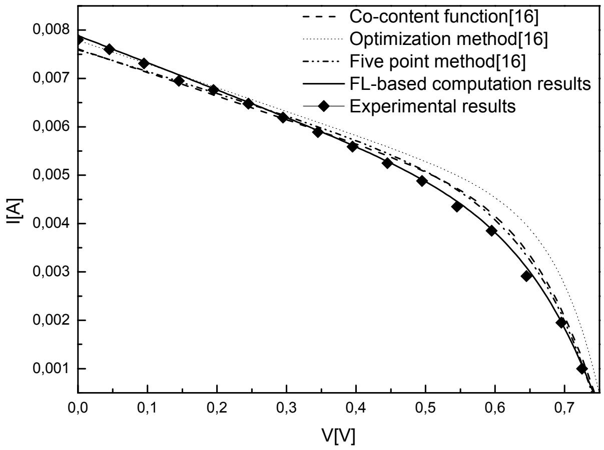


Fig. 2. Comparison between I–V characteristics of the investigated organic solar cell using the various approaches

Table.1 shows the comparison between the extracted parameters using our FL-based computation and the different extraction methods [16].

In order to find the model that best describes the organic solar cell, we have constructed simulated *I–V* plots based on the analytical model given in (1) according to the extracted parameters of each method, and compared the simulated plots to the experimental results [16], as it is shown in Fig. 2, where a good agreement between the experimental and our results is found. The statistical accuracy of our FL-model indicates that the best fit of *I–V* characteristic is obtained with our FL-computation method. Table.2 gives a comparison of the CPU (central processing unit) time requirements, the accuracy and the model limitations for the organic solar cell parameters extraction with those obtained from numerical and manual computations [14,16], where the proposed FL-based computation time should be compared to the orders of magnitude increase in computation time, accuracy and model limitations for more rigorous parameters extraction techniques, such as those based on the manual and numerical parameters computation. In this context, the proposed FL-based approach can be extended to study the double diode solar cell model by including new measurements and

TABLE I
THE EXTRACTED PARAMETERS USING OUR FL-BASED COMPUTATION AND OTHER APPROACHES

| Parameters | Co-content function [16] | Optimization method [16] | Five-point method [16] | FL-method |
|---|---|---|---|---|
| Rs(Ω) | 8.59 | 0.804 | 1.0277 | 5.22 |
| Rsh(Ω) | 197.23 | 203.25 | 221.73 | 174.3 |
| Iph(mA/cm2) | 7.94 | 7.82 | 7.63 | 7.88 |
| I0 (nA/cm2) | 13.6 | 13.6 | 957 | 421 |
| n | 2.31 | 2.32 | 3.45 | 3.20 |


ISBN: 978-988-19252-8-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

TABLE II
COMPARISON BETWEEN THE VARIOUS APPROACHES USED FOR THE SOLAR CELL PARAMETERS EXTRACTION

| Performances / Model | Computation time | Accuracy | Model limitation |
|---|---|---|---|
| FL-based model | Seconds | More accurate | Not limited |
| Numerical-based model[14, 16] | hours | Accurate | Not limited |
| Manual-based model | days | Less accurate | Limited |

experimental data.

The obtained results can be explained by the fact that the FL-based techniques are characterized as behavioural modeling approaches, in which the computational models are based on parallel distributed processing of data. Hence, the fuzzy computation provides practical insight into solar cells modeling and identification to design photovoltaic panels without the uncertain accuracy or meticulous tuning effort that face more rigorous solar cell models. The FL-based computation is a step towards a new generation of simulation tools that will allow solar cells and photovoltaic panel engineers to explore new classes of photovoltaic devices.

## IV. CONCLUSION

In this paper, a new simple and powerful approach based on Fuzzy Logic computation for organic solar cells parameters extraction was proposed. The parameters extraction of organic solar cell model was completed in a relatively short time, with no need for user intervention during the search. In addition, the proposed approach is useful for the accurate and easy extraction of solar cell parameters from a measured I–V characteristic. It is to note that the proposed approach can be extended to include other design and environmental parameters like: temperature effect, organic transport mechanisms, metal contact resistances and double-diode effect. However, new measurements and complex compact models which include these parameters should be developed. The encouraging comparisons between experimental results and our analytical simulations have indicated that the proposed approach is expected to be useful in the development of an accurate solar cell simulator to study the photovoltaic systems.

## REFERENCES

[1] M. Green, K. Emery, K. Buecher, D.L. King, S. Igari, Progress in Photovoltaics : Res. Appl 5, 51, 1997.
[2] H. J. Lewerenz and H. Jungblut, Photovoltaic -Grundlagen und Anwendungen, Springer, Berlin, Hei-delberg, New York (1995).
[3] M. Tivanov, A. Patryn, N. Drozdov, A. Fedotov and A. Mazanik, "Determination of solar cell parameters from its current–voltage and spectral characteristics". Sol. Energy Mater.Sol. Cells, vol. 87, pp. 457-465, 2005.
[4] EwaRadziemska. 'Dark I–U–T measurements of single crystalline silicon solar cells'. Energy Convers. Manage, vol.46,pp. 1485-1494, 2005.
[5] T. Jeranko, H. Tributsch, N.S. Sariciftci, J.C. Hummelen, Sol. Energy Mater. Sol. Cells, vol. 83, pp. 247–262, 2004.
[6] J. A. Jervase, H. Bourdoucen and A. Al-Lawati, Solar cell parameter extraction using genetic algorithms, Meas. Sci. Technol, vol. 12, pp. 1922–1925, 2001
[7] M. Ye, S. Zeng, and Y. Xu, An Extraction Method of Solar Cell Parameters with Improved Particle Swarm Optimization, China Semiconductor Technology International Conference 2010 (CSTIC 2010), March 18 - March 19, 2010, Shanghai, China.
[8] W. Kim, W. Choi, A novel parameter extraction method for the one-diode solar cell model, Solar Energy, vol 84, pp1008–1019, 2010.
[9] A. Maoucha, F. Djeffal, D. Arar, N. Lakhdar and T. Bendib and M.A. Abdi, An accurate Organic solar cell parameters extraction approach based on the illuminated I–V characteristics for double diode modeling, IEEE-REVET' 2012, Hammamet, Tunisia, 26-28 March, 2012, pp. 74-77.
[10] A. Cheknane, H. S. Hilal, F. Djeffal, B. Benyoucef, J-P. Charles, An equivalent circuit approach to organic solar cell modelling, Microelectronics Journal, vol. 39, pp. 1173–1180, 2008.
[11] RR. Yager, LA. Zadeh, An introduction to fuzzy logic applications in intelligent systems. Norwell, MA: Kluwer, 1991.
[12] K. Mishra, I. G. Sarma, and K. N. Swamy, Performance evaluation of two fuzzy-logic-based homing guidance schemes, J. Guid.,Control,Dyna., vol. 17, pp. 1389–1391, 1994.
[13] M. Esposito, G. D. Pietro, An ontology-based fuzzy decision support system for multiple sclerosis, Engineering Applications of Artificial Intelligence, vol. 24, pp. 1340-1354, 2011.
[14] J. Nocedal and S.J. Wright, Numerical Optimization, Second Edition, Springer Series in Operations Research, Springer Verlag, 2006.
[15] Z. Chunfu, Z. Jincheng, H. Yue, L. Zhenhua and Z. Chunxiang, A simple and efficient solar cell parameter extraction method from a single current-voltage curve, J. Appl. Phys, vol 110, pp. 064504-064504-7 (2011).
[16] A. Ortiz-Conde, FJ. Garcia Sanchez, J.Muci, New method to extract the model parameters of solar cells from the explicit analytic solutions of their illuminated I–V characteristics. Solar Energy Mater Solar Cells, vol. 90, pp. 352–61, 2006.