Software tool for the extrapolation to Standard Test Conditions (STC) from experimental curves of photovoltaic modules

J. Montes-Romero, M. Torres-Ramírez, J. de la Casa
IDEA Research Group, University of Jaen,
Campus Lagunillas, 23071 Jaen, Spain
J. Montes: jmontes@ujaen.es

A. Firman, M. Cáceres
GER – Grupo en Energías Renovables - FaCENA – UNNE,
Av. Libertad 5470 – 3400 Corrientes. Argentina

***Abstract*—A key aspect for the teaching of the photovoltaic technology is that the student perform experimental practices of measure the characteristic Current-Voltage (I-V) under natural sunlight of a photovoltaic cell, module or generator and, later, being able to extrapolate the extracted results into Standard Test Conditions (STC).**

This paper presents a software tool (*gotoSTC*) to facilitate the acquisition of this knowledge and support the learning process of our students.

***gotoSTC* allows processing experimental data from I-V curves and applies some of the accepted methods by the scientific community. The program has two functional options: on the first one, the characteristic parameters of one curve will be obtained from its I-V curve and STC extrapolation methods are applied to it; in the second option, a set of I-V curves of the same module are necessary to obtain the characteristic parameters and then applies the extrapolation methods. Graphical representations of the data are showed in order to present some of the existing relations between the parameters characterizing the device behavior.**

Keywords—Photovoltaic solar energy; software; LabVIEW; I-V curve; educational tool; extrapolaction to STC .

I. INTRODUCTION

Undoubtedly, the photovoltaic solar energy is part of the knowledge to be taught in any qualifications related to Renewable Energies, both in Secondary Education and the Bachelor and Master of our Universities. Creating educational environments that could be able to help the comprehension of specific aspects of technology should be part of the work developed by professors and university researchers; a transfer of knowledge that interrelate research work and teaching responsibilities.

In this work, a tool developed in LabVIEW© [1] which aims to support teaching/learning different methods of extrapolation to Standard Test Conditions (STC) is presented and, furthermore, helping in the understanding of basic concepts related to photovoltaic technology.

II. BACKGROUND

The PV module or photovoltaic generator is the main component of any photovoltaic system, either autonomous, grid-connected, or hybrid. This device is responsible for transforming the energy from the sun into electrical energy.

In fig. 1, the typical I-V curve of a photovoltaic element is shown. This characteristic I-V curve is composed by infinite pairs of current and voltage points. All of them are obtained varying the impedance connected to the module between zero to infinity. In the fig. 1 the most interesting points are also highlighted. The value of the parameters will depend on the module characteristics and the operating conditions to which has been acquired.

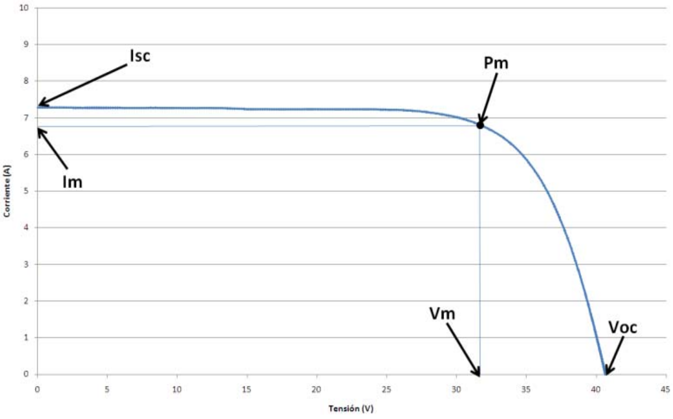


Fig 1. Characteristic I-V curve from a photovoltaic module and its main points of interest.

To characterize their products, manufacturers of PV modules will provide the value of the characteristic electrical parameters from which it is possible to estimate their basic behavior.

The main electrical technical data provided by manufacturers is shown in Table I. The value of these parameters is obtained when the module works in what is known as STC. These conditions, defined in standard IEC 60891, are shown in Table II.

TABLE I. ELECTRICAL TECHNICAL CHARACTERISTICS OF PHOTOVOLTAIC MODULES PROVIDED BY MANUFACTURERS.

Pm	Module maximum power (W)
Vm	Module voltage at maximum power in STC (V)
Im	Module current at maximum power in STC (A)
Voc	Module open circuit voltage (V)
Isc	Module short circuit current (A)

TABLE II. STANDARD TEST CONDITIONS.

Normal irradiance (*G*)	1000W/m^2
Cell temperature (*Tc*)	25ºC
Solar spectrum	AM1.5

In addition, some temperature coefficients are provided in order to know the variation of the main characteristic points depending on the operating temperature of the module (Table III).

TABLE III. TEMPERATURE COEFFICIENTS.

α	Short circuit current temperature coefficient (%/ºC)
β	Open circuit voltage temperature coefficient (%/ºC)
γ	Maximum power temperature coefficient (%/ºC)
NOCT	Normal Operate Cell Temperature. Operating temperature when normal irradiance is 800 Wm^{-2} and ambient temperature is 20ºC.

The present paper is focused on the analysis of the curve I-V as an essential aspect for the understanding of the photovoltaic technology. From I-V curve can be obtained all parameters which allow the proper characterization of the module and verify that the data provided by the manufacturer correspond with reality. It is also a key experiment that allows obtaining reliable information on the actual power of a PV generator and hence detect problems, or to estimate the production of the generator.

There are two main procedures that allow us to obtain the characteristic curve of a photovoltaic module: Laboratory measurements using solar simulators [2]; and outdoor measures or under real sunlight, which allow us a characterization that will be referred as Real Sunlight Conditions (RSC). Both systems have advantages and disadvantages that should be considered in choosing the method to be used.

A solar simulator is a system that has a lamp power of high precision and capable of recreating the solar spectrum. Must be taken into account that using solar simulators are experiments within the laboratory, so standard test conditions can be recreated easily. Therefore, the IV curve obtained using this type of equipment is performed to the same operating conditions the manufacturers characterize their products. The main drawback of solar simulators is the high cost of the system and also this procedure, for obvious reasons, is not applicable in case of measuring photovoltaic systems installed outdoor. In fig. 2, one of these systems can be seen.

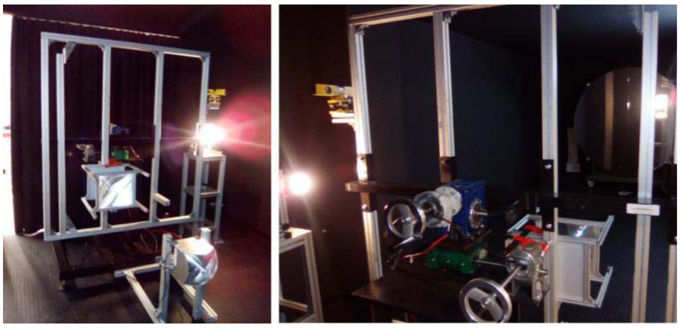


Fig 2. Solar simulator installed at the University of Jaen. On the left, front of the simulator is shown and on the right, the back to the simulator.

The RSC characterization is done by sun exposure PV module as seen in the example of fig.3, so no special equipment will be needed apart from the IV curve tracer [3][4][5] necessary for both methods. Obtain the curves in this way will be much less expensive, but it will be extremely difficult to find environmental conditions that allow the photovoltaic module work on STC, so it is necessary to use mathematical extrapolation methods to know electrical characteristics in STC from RSC experimental measures.

Fig 3. Solar tracker installed at the University of Jaen for the characterization of different PV modules in RSC.

In addition, together with the pairs of V-I values that shape the curve, it will also be necessary to obtain the value of the present meteorological variables when the I-V curve was obtained, which will influence the behavior of any photovoltaic generator. Fundamentally, and the level of precision at hand, the parameters needed will be incident irradiance and temperature. To achieve a higher level of precision, the cell temperature is measured instead of calculate it from ambient temperature.

The essential parameters to extract from the experimental characteristic I-V curve are: short circuit current (*Isc*), open circuit voltage (*Voc*) and maximum power (*Pm*). With these basic parameters it is possible to use some extrapolation methods [6], with the help of some other auxiliary data that can be extracted from the I-V curve or are provided by the manufacturer (α, β, γ).

In addition to providing the characteristic parameters, the curve I-V provides through its shape, information for detecting anomalies in a PV module such as degradation, fractured cells, shading [7], mismatches [8] or hot spots. A defect or deformation of the expected curve means that the module has a fault and this can affect the proper operation and power of the PV [9] system [10] [11].

In conclusion, the most economical method for the characterization of PV modules is plotting curve I-V in RSC, so to normalize the information obtained through this procedure, it is necessary to study the different methods to extrapolate into STC.

III. DESCRIPTION OF EXTRAPOLATION METHODS TO STC IMPLEMENTED ON GOTOSTC.

There are published and accepted by the scientific community, a large number of procedures that attempt to answer the extrapolation to STC. These methods can be classified into two main groups:

- Algebraic procedures
- Numeric procedures

Both model the behavior of these semiconductor devices for input conditions (external parameters of meteorological type) depending on their intrinsic and / or technological characteristics. The second require much greater calculus capacity than the first one and there is a widespread idea that they are much more precise and accurate. In this case, we have decided to implement in *gotoSTC* both algebraic and numerical procedures.

Algebraic methods chosen for use in the application are: Araujo [12], constant Fill Factor and Osterwald [13]; while the numerical procedure used is the GER [14]. The first three methods perform calculations only for obtaining characteristic parameters of the PV module. The GER method, being a numerical method, make a reconstruction of the I-V curve with which it is possible to obtain all characteristic parameters that can provide a I-V curve and the electrical equivalent model.

The purpose is to use methods that, being simple, can achieve a good extrapolation results. Must be taken into account that there are more accurate methods of extrapolation to STC [15] [16], but due to its complexity has not thought it appropriate to use for educational activities.

The main proposal is to provide simple methods in order to allow students to perform extrapolation calculations manually during their studies without the need for excessively complex calculations, so *gotoSTC* tool can also be used to compare the results manually performed by the student with those obtained by the tool. This will help students and facilitate learning these extrapolation techniques which are necessary in work related to photovoltaic systems.

Furthermore, to simple algebraic methods, it was added to the tool a numeric procedure in order to be shown the main differences between algebraic procedures, where you can only obtain the characteristic parameters, and numeric procedures, where the whole I-V curve is simulated, giving the possibility to compare the complete I-V curve with the one obtained experimentally.

Three algebraic and one numeric procedures to extrapolate to STC have been chosen to be included in *gotoSTC* tool, so that each of them is briefly described below.

Araujo's method. Approach the values of cell voltage (V_M) and current (I_M) in the maximum power point from short circuit current (I_{SC}) and open circuit voltage (V_{OC}) using (1) and (2), with which you can obtain the maximum power (P_M) of the cell.

$$Isc = \frac{G}{G^*} \cdot I_{SC}^* \tag{1}$$

$$Voc = V_{OC}^* - \beta \cdot (T_C - 25) \tag{2}$$

$$V_M = V_{OC} \left[1 - \frac{b}{v_{oc}} \cdot \ln a - r_s \cdot (1 - a^{-b}\right] \tag{3}$$

$$I_M = I_{SC}(1 - a^{-b}) \tag{4}$$

$$r_s = 1 - \frac{FF^*}{FF_0} \tag{5}$$

$$a = v_{oc} + 1 - 2 \cdot v_{oc} \cdot r_s \tag{6}$$

$$b = \frac{a}{1+a} \tag{7}$$

$$v_{oc} = \frac{V_{OC}}{K \cdot T_c} \cdot e \tag{8}$$

$$FF_0 = \frac{v_{oc} - \ln(v_{oc} + 0.72)}{v_{oc} + 1} \tag{9}$$

where:
r_s = normalised cell series resistance;
FF^* = fill factor in STC;
u_{OC} = normalised open circuit cell voltage;
K = Boltzmann's constant = $1{,}38 \cdot 10^{-23}$ J·K^{-1};
e = $1{,}602 \cdot 10^{-19}$ C.

Constant Fill Factor's method (FFk). This method assumes the fill factor remains constant through all operating conditions. As in the Araujo's method, both cell short-circuit current and open-circuit voltage vary linearly with incident global irradiance and cell temperature, respectively, according to (1) and (2). This way, using (10) can approximate the value of maximum power (P_M).

$$P_M = FF \cdot Voc \cdot Isc \tag{10}$$

Osterwald's method. This method accounts for being one of the simplest, and achieve a good estimation of maximum power (P_M).

$$P_M = P_M^* \cdot \frac{G}{G^*}[1 - \gamma \cdot (T_C - 25)] \tag{11}$$

where:
G = incident global irradiance (W·m–2);
G^* = incident global irradiance in STC (1000 W·m–2);
P_M = maximum power (W);
P^*_M = maximum power in STC (W);
T_C = cell temperature (ºC);
γ = maximum power temperature coefficient (ºC^{-1}).

GER's method. This method is based on a five parameters electrical model [17], where the simulation of the I-V curve will be held and the parameters to be determined can be extracted. Using the equations (1) and (2) to obtain the open circuit voltaje (V_{OC}) and the short circuit current (I_{SC}) in STC, the equation (12) is needed to calculate the thermal voltage (V_t) and the methodology described in [9] to find the series resistance (R_s) and the shunt resistance (R_{sh}). The value of current (I) can be obtained for each voltage (V) value using equation (13).

$$Vt = \frac{K \cdot Tc}{q} \tag{12}$$

$$I = Isc\left(1 - e^{\frac{V - Voc + I \cdot Rs}{m \cdot N \cdot Vt}}\right) - \frac{V + I \cdot Rs}{Rsh} \tag{13}$$

where:
Vt = thermal voltage;
Rs = series resistance;
Rsh = shunt resistance;
m = diode ideality factor;
N = number of series cell;
q = 1,602·10^{-19} C.

IV. INSTALLATION AND USE OF *GOTOSTC*

The tool has been designed to process I-V curves of photovoltaic modules, so will require data files containing each of the I-V curves previously obtained experimentally. The format of the input files must be ".csv" but its configuration can adjust so that it is possible to use data files from multiple curve tracers, both commercial [5] as own development [4]. The minimum data for the proper functioning of the program that data files must contain are the following: the pairs of points of voltage and current that will shape the curve, the incident irradiance and ambient or module temperature to which they have been obtained this I-V curve. These data should be gathered in columns.

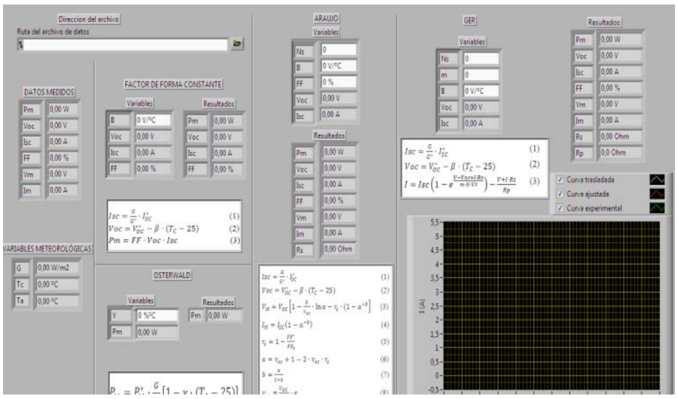
In the application is possible to configure the data extraction from experimental curves, so that it is possible to select in which column will be found each of the data groups from all the parameters. It is also possible to configure the separator between columns, being able to choose *";"* or tab. There is no file size limitation, allowing any number of rows and columns, as they have the above mentioned minimum parameters, because they will be necessary for the application of the methods described. Before start using the tool, it must be configured correctly to suit the curves that are to be used.

The tool is divided into two main parts: one where a single I-V curve is taken and the extrapolation methods discussed above are applied; and a second part where set of curves is taken to extrapolate them and the results are shown by a graph, in addition to providing the average of the characteristic parameters obtained in all I-V curves. Each of the parts of the program has a different purpose. The first part is designed in order to students can learn the methods of extrapolation to STC and observe their differences. In the second part, the main aim is to observe the existing relations between the obtained parameters in a graphic and easy way.

The figure 4 shows the part of extrapolation of a single curve. On the first place the file containing the experimental data of the I-V curve to be treated is chosen. Once selected, you can see on the left side of the application, the characteristic parameters in real sunlight conditions extracted from the I-V curve. Then, the extrapolation methods to STC in the application can be found.

For each of the methods few variables and results are observed. The variables are all parameters that are necessary for the implementation of the method, the minimum input data required by each method. Some of the variables cannot be modified due to they are extracted directly from the I-V curve used; therefore many of these parameters match with the values shown on the left side of the program. The reason to show again these variables is for the student to learn what parameters are necessary for the implementation of each of the methods.

It is also necessary to include some other parameters that can be modified, since it is not possible to obtain from I-V curve, so they should be provided by the student using the data sheet of the module manufacturer. These parameters are the open circuit voltage temperature coefficient (β), the maximum power temperature coefficient (γ), the number of series cell present in the module (Ns) and the Fill Factor expected in STC (FF). There is other parameter which does not appear in the data sheet: the diode ideality factor (m). This parameter is estimated from cell technology used in the module. These data can be modified; changing the results obtained, and may determine the influence of each on extrapolation methods.



DATOS MEDIDOS: Pm 0,00 W; Voc 0,00 V; Isc 0,00 A; FF 0,00 %; Vm 0,00 V; Im 0,00 A

VARIABLES METEOROLÓGICAS: G 0,00 W/m2; Tc 0,00 ºC; Ta 0,00 ºC

FACTOR DE FORMA CONSTANTE – Variables: B 0 V/ºC; Voc 0,00 V; Isc 0,00 A; FF 0,00 % – Resultados: Pm 0,00 W; Voc 0,00 V; Isc 0,00 A; FF 0,00 %

OSTERWALD – Variables: V 0 %/ºC; Pm 0,00 W – Resultados: Pm 0,00 W

ARAUJO – Variables: Ns 0; B 0 V/ºC; FF 0 %; Voc 0,00 V; Isc 0,00 A – Resultados: Pm 0,00 W; Voc 0,00 V; Isc 0,00 A; FF 0,00 %; Vm 0,00 V; Im 0,00 A; Rs 0,00 Ohm

GER – Variables: Ns 0; m 0; B 0 V/ºC; Voc 0,00 V; Isc 0,00 A – Resultados: Pm 0,00 W; Voc 0,00 V; Isc 0,00 A; FF 0,00 %; Vm 0,00 V; Im 0,00 A; Rs 0,00 Ohm; Rp 0,0 Ohm

☑ Curva trasladada
☑ Curva ajustada
☑ Curva experimental

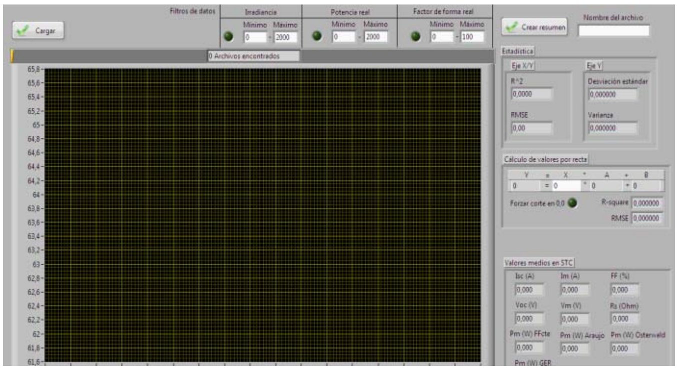
Fig 4. Part of the *gotoSTC* tool responsible for extrapolating a single experimental I-V curve.

Each method will include the expressions used for its implementation, in order to know how the result is obtained.

Furthermore, the GER method performs a numerical procedure that provides the reconstruction of I-V curve. The curves obtained are graphically displayed, being possible to observe the experimental curve obtained from the data file, the fitted curve from the method under the same environmental conditions to which the experimental curve was taken, and the curve extrapolated to STC also indicating its maximum power point. This way the student can appreciate the difference between a curve taken experimentally and a curve plotted from numerical methods.

The same methods mentioned above will be performed for part of extrapolation of multiple curves. After selecting the folder containing the desired files and activating button, it will start loading the files. The loading time of this process depends mainly on the size of the files containing the data. Once the charging of the curves ends, all de data are shown graphically. It is also possible to include data filters for irradiance, power and fill factor for these parameters taken into RSC. The purpose is to detect and eliminate wrong data. Mainly, you can find plotted curves with defects on the meteorological parameters measured, unwanted shading or any inconvenience that may change the expected result. The table of results shows the average of the STC values obtained by the methods performed.

In the graph, any data collected by the program can be represented, with the purpose to facilitate the understanding of the existing relations between the parameters that affect the behavior of PV modules. In this part of the program, can be also created a summary file that contains all the parameters obtained from the data files to use the results with other systems.



Irradiancia: Mínimo 0, Máximo 2000
Potencia real: Mínimo 0, Máximo 2000
Factor de forma real: Mínimo 0, Máximo 100

0 Archivos encontrados

Eje X/Y: R^2 0,0000; RMSE 0,00
Eje Y: Desviación estándar 0,000000; Varianza 0,000000

Y = X * A + B: 0 = 0 * 0 + 0
Forzar corte en 0,0 ●
R-square 0,000000
RMSE 0,000000

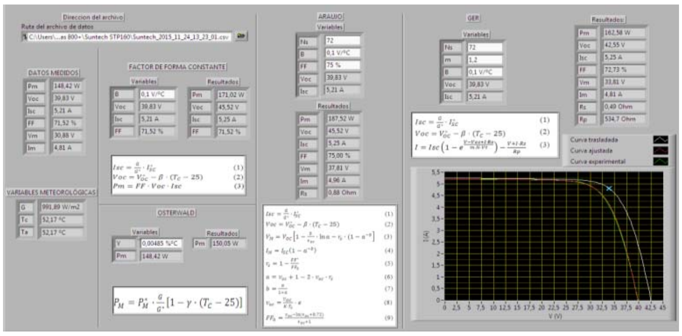
Valores medios en STC: Isc (A) 0,000; Im (A) 0,000; FF (%) 0,000; Voc (V) 0,000; Vm (V) 0,000; Rs (Ohm) 0,000; Pm (W) FFcte 0,000; Pm (W) Araujo 0,000; Pm (W) Osterwald 0,000; Pm (W) GER

Fig 5. Part of the *gotoSTC* tool responsible for extrapolating multiple experimental I-V curves.

V. RESULTS AND DISCUSSION

The tool has been tested with I-V curves of different PV modules technology; both in the part of extrapolation for a single curve and using multiple curves. Have also been compared the data obtained by *gotoSTC* tool and those obtained by other tools in order to verify that the results were similar, ensuring the proper functioning of the system. The part of the tool to extrapolate a curve responds well to change variables during use, being a little more noticeable change of variables GER method due to the number of operations is far greater than the other methods used and may notice a slight waiting time to update its results.

In fig. 6 an example of use of the tool is presented. In this part, extrapolation to a single curve is performed, being able to observe the characteristics described above. For the following examples the module used is a Suntech STP160 polycrystalline technology mounted on solar tracker shown in fig.3.



Ruta del archivo de datos: C:\Users\...as 800+\Suntech STP160\Suntech_2015_11_24_13_23_01.csv

DATOS MEDIDOS: Pm 148,42 W; Voc 39,83 V; Isc 5,21 A; FF 71,52 %; Vm 30,88 V; Im 4,81 A

VARIABLES METEOROLÓGICAS: G 991,89 W/m2; Tc 52,17 ºC; Ta 52,17 ºC

FACTOR DE FORMA CONSTANTE – Variables: B 0,1 V/ºC; Voc 39,83 V; Isc 5,21 A; FF 71,52 % – Resultados: Pm 171,02 W; Voc 45,52 V; Isc 5,25 A; FF 71,52 %

$Isc = \frac{G}{G^*}\cdot I_{SC}^*$ (1)
$Voc = V_{OC}^* - \beta\cdot(T_C-25)$ (2)
$Pm = FF\cdot Voc\cdot Isc$ (3)

OSTERWALD – Variables: Y 0,00485 %/ºC; Pm 148,42 W – Resultados: Pm 150,05 W

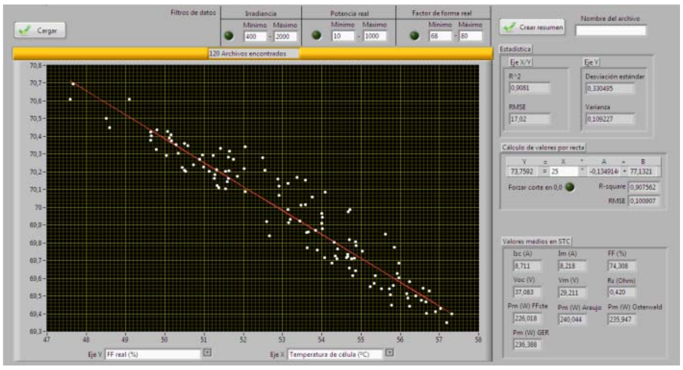
$P_M = P_M^*\cdot\frac{G}{G^*}[1-\gamma\cdot(T_C-25)]$

ARAUJO – Variables: Ns 72; B 0,1 V/ºC; FF 75 %; Voc 39,83 V; Isc 5,21 A – Resultados: Pm 187,52 W; Voc 45,52 V; Isc 5,25 A; FF 75,00 %; Vm 37,81 V; Im 4,96 A; Rs 0,88 Ohm

GER – Variables: Ns 72; m 1,2; B 0,1 V/ºC; Voc 39,83 V; Isc 5,21 A – Resultados: Pm 162,58 W; Voc 42,55 V; Isc 5,25 A; FF 72,73 %; Vm 33,81 V; Im 4,81 A; Rs 0,49 Ohm; Rp 534,7 Ohm

Fig 6. Example of part of the *gotoSTC* tool responsible for extrapolating a single experimental I-V curve.

Below, in fig. 7 Example of the part of the tool where multiple curves are analyzed is presented. In the exposed example is possible to appreciate the graph of relationship between the measured fill factor in RSC and cell temperature registered for each plotted I-V curve, being able to observe the relationship between both parameters, as well as using the linear fit adjustment for approximately calculate a value, as can be seen in the example of fig.7, the fill factor at 25ºC.



Irradiancia: Mínimo 400 - Máximo 2000
Potencia real: Mínimo 10 - Máximo 1000
Factor de forma real: Mínimo 68 - Máximo 80
Nombre del archivo:
120 Archivos encontrados
R^2: 0,9081
RMSE: 17,02
Desviación estándar: 0,330495
Varianza: 0,109227
Y = X * A + B: 73,7592 = 25 * -0,134914 + 77,1321
Forzar corte en 0,0
R-square: 0,907562
RMSE: 0,100907
Isc (A): 8,711
Im (A): 8,218
FF (%): 74,308
Voc (V): 37,083
Vm (V): 29,211
Rs (Ohm): 0,420
Pm (W) FFcte: 226,018
Pm (W) Araujo: 240,044
Pm (W) Osterwald: 235,947
Pm (W) GER: 236,388
Eje Y: FF real (%)
Eje X: Temperatura de célula (ºC)

Fig 7. Example of the part of the *gotoSTC* tool responsible for extrapolating multiple experimental I-V curves.

VI. CONCLUSIONS

There has been a tool that can be used both for teaching purposes in any kind of education related to photovoltaic technology and research work, allowing quick and comprehensive analysis of a set of experimental curves.

It is characterized by its simplicity of operation. It is supported with theoretical material that allows students to settle knowledge of how the process of extrapolation to STC is done through several algebraic methods with very low computational complexity. Besides learning extrapolation methods, it could also help as graphic support in teaching explanations through the corresponding part of the program. With this, a large number of explanations of the existing relations between different characteristic parameters extracted directly from the I-V curve, meteorological variables and parameters extrapolated to STC.

The gotoSTC tool has started to be used in Bachelor and Master subjects directly related to PV technology during the current quarter. To evaluate whether the application has been successful helping the student, surveys will be carried to users about the application. The questions will be related to the ease of program usage, the assistance provided in the understanding of knowledge, possible improvements or defects which may be found, etc.

ACKNOWLEDGEMENT

This communication, besides being considered by the authors as part of their work, and which is intended to demonstrate the importance of the binomial Research-Teaching should always coexist in a university professor, has been promoted, partly funded and is part of the work in the framework of two technology transfer projects:

- **Acciones de cooperación al desarrollo en el marco de la transferencia del conocimiento a universidades iberoamericanas. Caso de estudio: caracterización a sol real de módulos FV utilizando equipamiento de bajo coste**, funded by 'Plan Plurianual de I+D' from 'Centro de Estudios Avanzados en Energía y Medio Ambiente' of the University of Jaen.
- **EMERGIENDO CON EL SOL. Apoyo institucional al Centro de Energías Renovables de la Universidad Nacional de Ingeniería de Lima (Perú) en el campo de la generación de energía eléctrica empleando tecnología fotovoltaica,** funded by the program of 'Proyectos de Cooperación Internacional para el Desarrollo de la Agencia Andaluza de Cooperación Internacional'.

REFERENCES

[1] National Instruments, http://www.ni.com/labview/ LabVIEW, National Instruments Website.

[2] International Electrotechnical Commission. Standard IEC 60904-9: Photovoltaic Devices. Part 9: Solar Simulator Performance Requirements. IEC Central Office: Geneva, Switzerland, 2007.

[3] Duran, E., Piliougine, M., Sidrach-De-Cardona, M., Galan, J., & Andujar, J. M. (2008). Different methods to obtain the I-V curve of PV modules: A review. Conference Record of the IEEE Photovoltaic Specialists Conference. http://doi.org/10.1109/PVSC.2008.4922578

[4] Neuenstein J., Podewils C (2009). "Los módulos y sus curvas." Photon. La revista de fotovoltaica, pp. 54-71.

[5] J.V. Muñoz, J. de la Casa, M. Fuentes, J. Aguilera, J.C. Bertolin. "NEW PORTABLE CAPACITIVE LOAD ABLE TO MEASURE PV MODULES, PV STRINGS AND LARGE PV GENERATORS". Procedings of 26th European Photovoltaic Solar Energy Conference 4276- 4280

[6] IEC 60891. "Photovoltaic Devices. Procedures for Temperature and Irradiance Corrections to Measure I-V Characteristics". 2nd edn, International Electrotec

[7] García, M., Maruri, J. M., Marroyo, L., Lorenzo, E. and Pérez, M. (2008), Partial shadowing, MPPT performance and inverter configurations: observations at tracking PV plants. Progress in Photovoltaics

[8] D. Picault, B. Raison, S. Bacha, J. de la Casa, J. Aguilera, Forecasting photovoltaic array power production subject to mismatch losses, Solar Energy, Volume 84, Issue 7, July 2010, Pages 1301-1309, ISSN 0038-092X,

[9] Sanchis, P., López, J., Ursúa, A., Gubía, E. and Marroyo, L. (2007), On the testing, characterization, and evaluation of PV inverters and dynamic MPPT performance under real varying operating conditions. Prog. Photovolt: Res. Appl., 15: 541–556. doi:10.1002/pip.763

[10] M.A. Munoz, M.C. Alonso-García, Nieves Vela, F. Chenlo, Early degradation of silicon PV modules and guaranty conditions, Solar Energy, Volume 85, Issue 9, September 2011, Pages 2264-2274, ISSN 0038-092X

[11] Ryan M. Smith, Dirk C. Jordan, and Sarah R. Kurtz, Outdoor PV Module Degradation of Current-Voltage Parameters, 2012 World Renewable Energy Forum

[12] Araujo, G., Sánchez, E., 1982. Analytical expressions for the determination of the maximum power point and the fill factor of a solar cell. Solar Cells 5, 377–386.

[13] Osterwald, C.R., 1986. Translation of device performance measurements to reference conditions. Solar Cells 18, 269–279.

[14] Firman, A., Toranzos, V., Busso, A., Cadena, C., & Vera, L. (2011). "Determinación del Punto de Trabajo de Sistemas Fotovoltaicos Conectados a Red: Método Simplificado de Traslación Punto a Punto a Condiciones Estándar de Medida". Avances en Energías Renovables y Medio Ambiente, 15, 1-8.

[15] CEI 60891, Procedures for temperature and irradiance corrections to measuremend I-V characteristics of crystalline silicon photovoltaic devices, First edition 04-1987, Ginebra, 1987.

[16] 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, Volume 56, April 2016, Pages 494-509, ISSN 1364-0321

[17] J.I. Rosell, M. Ibáñez, Modelling power output in photovoltaic modules for outdoor operating conditions, Energy Conversion and Management, Volume 47, Issues 15–16, September 2006, Pages 2424-2430, ISSN 0196-8904,