

VIRTUAL INTERFACE AS AN EDUCATIONAL TOOL IN PHOTOVOLTAIC SYSTEMS WORKSHOPS

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Abstract— Aiming to cover some contents that it is not commonly found in the brazilian educational systems, the Universidade Federal de Campina Grande Power Electronics and Industry Applications Joint Societies Student Branch Chapter (UFCG PELS/IAS SBC) has offered opportunities to learning about photovoltaic (PV) systems using some didactic tools. This paper presents a Graphical User Interface (GUI) used as an educational tool in PV System Workshops. Some activities were done and data was collected. This paper shows details about the GUI developed, some results and conclusions of this experience.

Keywords— Photovoltaic System, Graphical User Interface, Educational Tool.

1 Introduction

The quality of education in engineering has always been connected to two levels of knowledge: theoretical and practical (Duro et al., 2008). During recent years, the traditional education system of the modern society has witnessed changes. The reasons for this lay is the global orientation of the world economy, strong competition and the change of the social structure (Hadzi-Kostova and Styczynski, 2004).

In the case of electrical engineering, many institutions for higher education throughout the world are developing and offering new teaching methods for the students, to cover some contents that does not fit in the engineering educational workload anymore. In the particular case of the renewable systems, the academic community has been showing the results of applying some teaching techniques: Project-Based Cooperative (Verbič et al., 2017), Project-Based Learning (Martinez-Rodrigo et al., 2017), Video-Sharing (Torres-Ramírez et al., 2014), Teaching using Industry-Standard Tools (Ochs and Miller, 2015), and Promoting STEM (Pecen and Nayir, 2010).

In this context, simulations compose notably a fundamental step in the process of learning power engineering themes. Besides that, the use of simulation does not require a physical plant or any specific device to collect data, being the most viable alternative for educational purposes when introducing energy systems theme (Pires and Silva, 2002), (Biczal and Michalski, 2009), (Tan and Teow, 2014).

Otherwise, simulation models may require

some knowledge of computational algorithms, numerical methods and advanced mathematics. These requirements effectively difficult the inclusion of some students or enthusiast in the area. To overcome this problem, some solutions has been explored in renewable systems applications: (Bayindir et al., 2011), (Delimustafic et al., 2011), (Dolan et al., 2011), (García et al., 2017). Notably, the use of virtual interfaces is recurrent as a key facilitation tool in the teaching process, not only for simulated systems, but also in several applications designed for teaching.

This paper presents a Graphical User Interface (GUI) used as an educational tool in Photovoltaic (PV) System Workshops. In these workshops, the students are presented to typical tools and concepts of PV systems. The GUI is used to facilitate the analyses of the mathematical modeling of PV modules. The authors appoint this feature as a differential in comparison with other softwares available in the market. The user does not need to know the mathematical equations or even compose some algorithm, as it is masked by the interface.

The most part of the softwares related are directed to structural design dimensioning and economic evaluations. The proposed GUI allow the users fill some informations and plot the characteristic curve of a PV module and, at the same time, make some analysis.

The paper is structured as follows: section 2 the workshop is described; section 3 contains all the information about the GUI developed; section 4 gives the feedback and outcomes of the activities; section 5 the conclusions and future works.

2 Introduction to PV Systems Workshop

The Introduction to Photovoltaic Systems Workshop was promoted by the Universidade Federal de Campina Grande (UFCG) Power Electronics (PELS) and Industry Applications (IAS) Joint Societies Student Branch Chapter¹. In this paper, the group will be referred as UFCG PELS/IAS SBC or just SBC. PV systems are in evidence nowadays, thereby the SBC came up with the idea to introduce some students to PV systems.

The SBC promoted two editions of this Workshop up to the submission of this paper. The first edition had 20 participants and took eight hours. The second one had 13 participants and took 6 hours. The Workshop had four activities: theoretical lecture [Fig. 1(a)], grid connection experiment [Fig. 1(b)], PV generator inclination and orientation experiment [Fig. 1(c)], and simulation of a PV module [Fig. 1(d)].



Figure 1: The four activities of the Workshop: (a) Theoretical lecture; (b) Grid connection experiment; (c) PV generator inclination and orientation experiment; and (d) Mathematical model of a PV cell lecture.

As a part of the development of the Workshop, the volunteers made a PV System Manual and a GUI for PV modules modeling.

2.1 The Manual

Using various references about PV systems, the volunteers of the Workshop wrote a manual that synthesized many topics that were fragmented across some knowledge areas: history of PV systems worldwide and in Brazil, meteorology and

¹The Universidade Federal de Campina Grande (UFCG) Power Electronics (PELS) and Industry Applications (IAS) Joint Societies Student Branch Chapter was formed by a group of students from the Laboratory of Industrial Electronics and Machine Drives (LEIAM) in Campina Grande, Paraíba, Brazil. The UFCG PELS/IAS SBC is the first PELS SBC in Brazil. Its objectives are promoting PELS and IAS and organizing activities that will contribute to the development of its members.

the movement of the Earth around the Sun, materials and fabrication process of a PV cell, and mathematical modeling of PV cells, modules, and panels. As result, the volunteers produced an introductory manual to PV systems (Fig 2).

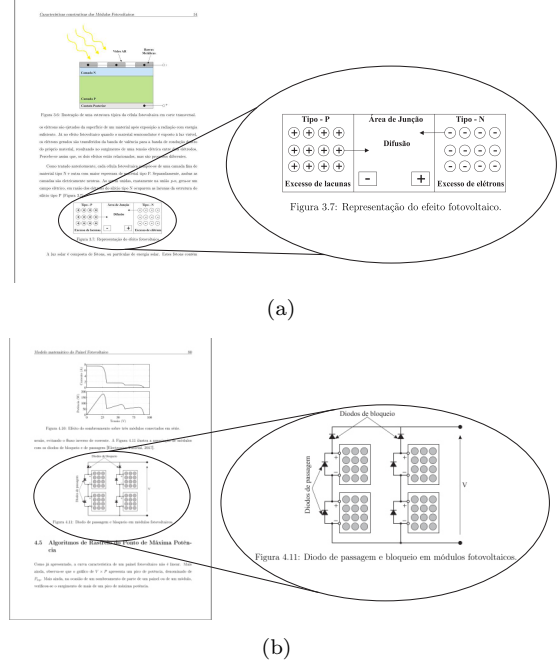


Figure 2: Some of the pages from the Manual: (a) Front cover; (b) PV cell constructive characteristics section; and (c) Partial shading section.

2.2 The Lectures

The theoretical lecture presented the topics described in the manual. These are the key topics for an introductory workshop to PV systems. Some slides used during the lectures are shown in Fig. 3).

2.3 The Experiments

The experimental and simulation activities were held to review the key points presented during the theoretical lecture, which are the following:

- 1. Grid Connection Experiment:** At this moment some power inverters were used, ranging from 250 W through 1 kW. Each participant connected a PV module emulator to the grid using a commercial PV inverter, noticing the mains elements of the systems: maximum power point tracking, phase-locked loop, efficiency of the inverter, power quality etc;
- 2. Output Power vs. Inclination and Orientation Experiment:** In this part of the Workshop, a 140 W PV module was connected to a variable resistive load. Using the load, the participants could measure some key points of the PV module, such as: maximum power point voltage and current, short-circuit current and open circuit voltage. Also,

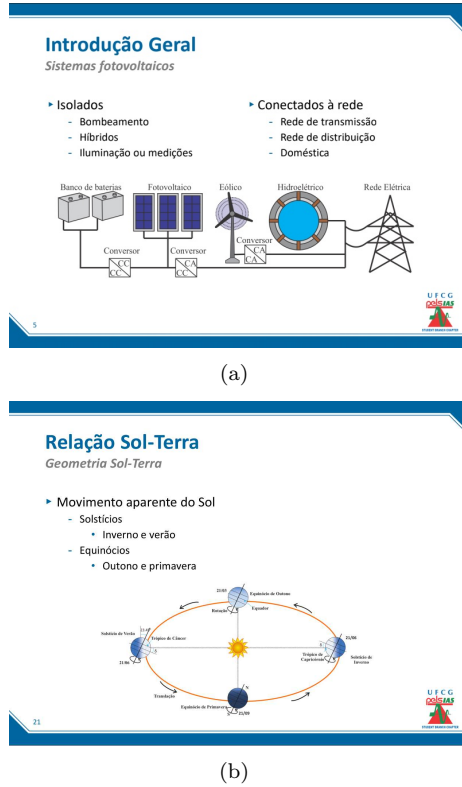


Figura 3: Some of the presentation slides: (a) General Introduction; (b) Earth translation around the Sun; (c) Photovoltaic cell single diode model; and (d) Influence of the irradiance on the output power of a PV module.

a discussion about the governmental regulations and challenges for the PV systems in Brazil was held;

The last activity was the simulation of a PV cell. Using the GUI made by the volunteers, the participants could study a PV module and how to model it. The interface allows the students to set some key parameters of a PV module, and to evaluate its output power under various irradiance and temperature conditions.

3 The Grafical User Interface

The study of the characteristic curves $I \times V$ and $P \times V$ is essential to understand the behaviour of a photovoltaic cell, module or panel. From the perspective of the user, the interface is a simple and visual tool that generates the characteristic curves $I \times V$ and $P \times V$ of a single or several connected modules. The user, with the interface, does not need programing the mathematical equations. A description of the developed GUI is given in this section. In Section 3.3 it is presented the case of study realized.

3.1 Description by Areas

As illustrated in Fig. 4, the interface is divided in four areas, numbered from I to IV. The first

area (I) is related to the intrinsic characteristics of the panel, the second (II) defines the test conditions, the third area (I) determines which one of the available analysis will be done, and the last one (IV) is the plot area.

3.1.1 Area I

In the area I, there are 4 sub-areas: I.a, I.b, I.c and I.d. In the sub-area I.a, the user has to select the electric model of the cell in the pop-up: "Selecione um modelo para o painel" (Select a model to the panel). It should be selected the option: "Modelo Detalhado com um diodo" (Detailed Model with one diode). For teaching purpose, a reduced model it is always considered a didactic choice for introductory contents. Besides that, this model is accepted as a good approximation in the specialized literature (Villalva et al., 2009), (Gomes et al., 2017).

In the sub-area I.b, the user has to fill the fields with the parameters of the module presented in the datasheet. The fields to be filled are: maximum power (P_{max}); voltage at the maximum power point (V_{mpp}); current at the maximum power point (I_{mpp}); number of cells connected in series (ns); nominal open-circuit voltage (V_{oc}); nominal short-circuit current (I_{sc}); current coefficient (ki); number of panels in series; number of panels in parallel.

The sub-area I.c has to be filled with the "Condições de Teste Padrão" (Standard Test Conditions) of Irradiance ($Irrad.$) and Temperature ($Temp.$). These values are also presented in the datahseet of the PV module.

In contrast with the previous sub-area, the sub-area I.d does not gather information directly from the datasheet. The ideality factor a is not commonly described on it. In the interface, the user has the option of directly filling the field, through the option "Digitar Manualmente" (Type manually) in the pop-up, or selecting it according with the material of the module, based on the values presented in (Natsheh and Albarbar, 2011).

3.1.2 Area II

The second area can be divided in two sub-areas: II.a and II.b. In the sub-area II.a, similarly to what occurs to the ideality factor, the fields R_s and R_p can be filled by the user or they can be estimated based on the method described in (Villalva et al., 2009). These two options can be chosen through the pop-up. The fields to be filled corresponding to the conditions of Irradiance ($Irrad.$) and Temperature ($Temp.$), under which the panel will work, are in sub-area II.b.

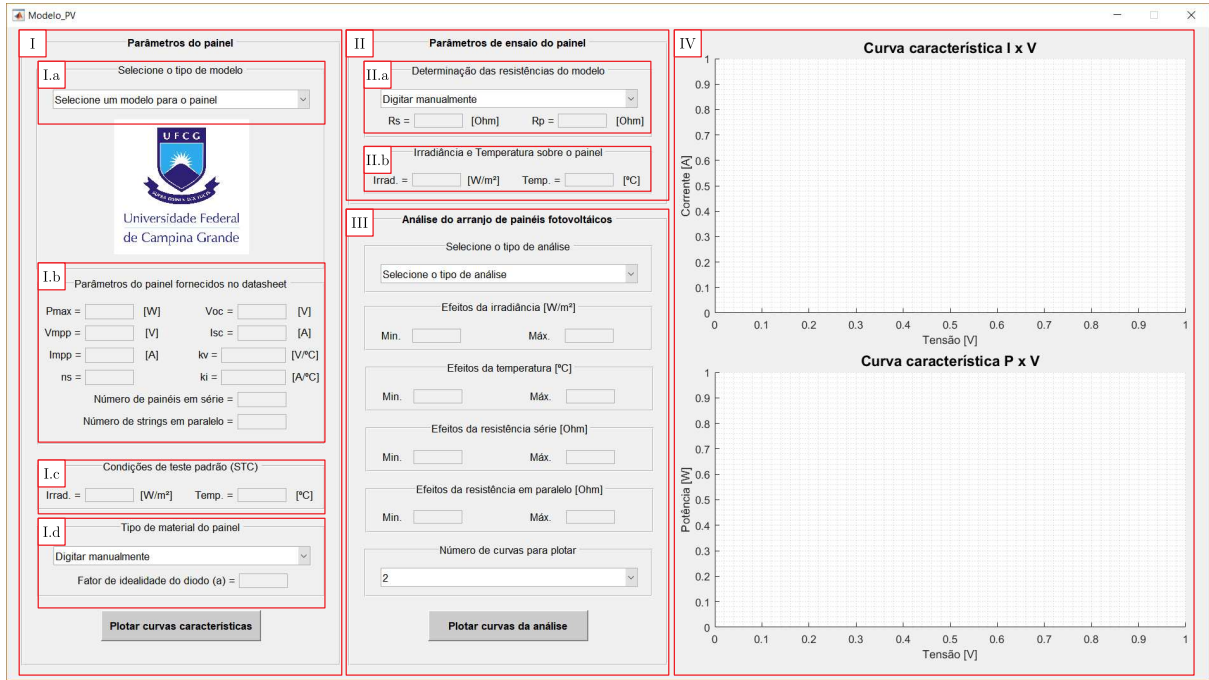


Figura 4: Blank GUI for simulating PV arrays.

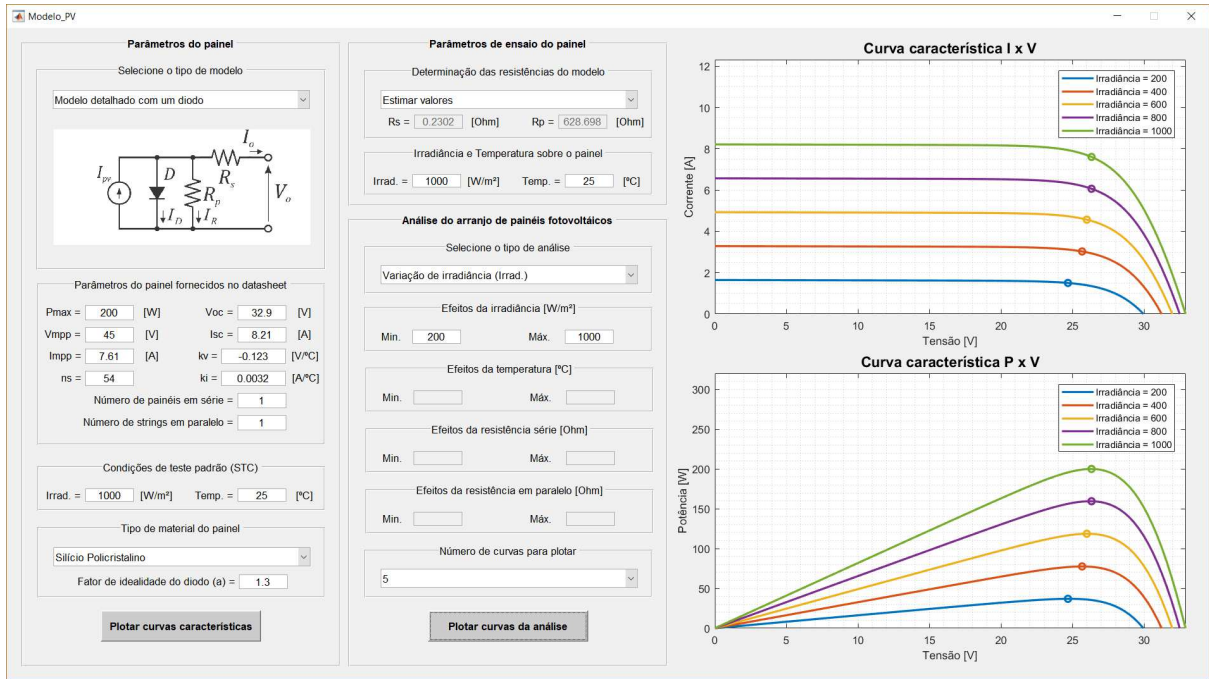


Figura 5: Filled GUI showing the characteristics curves of a PV panel.

3.1.3 Area III

In third area, the user has the option of change the values of Irradiance (*Efeitos da Irradiância*), Temperature (*Efeitos da Temperatura*), Series Resistance (*Efeitos da Resistência Série*) and Parallel Resistance (*Efeitos da Resistência Paralela*) in a specific range. Also, up to five characteristic curves $I \times V$ and $P \times V$ can be plotted simultaneously and analysed. The number of plots can be chosen through the pop-up "*Número de curvas*"

para plotar"(Number of plots). Once defined the analysis to be done and the number of plots, the user has only to press the button "*Plotar Curvas da análise*"(Plot curves to analyse) to generate curves. The Fig. 5 illustrates these analyses. In each curve, the respective maximum power point (I, V) or (P, V) is highlighted with a circle.

3.2 Exceptions and Error Handling

With all previous fields filled, the button "Plotar curvas características" (Plot the characteristic curves) can be pressed to generate the curves. If one of the fields was not filled or if it was done in a wrong way, the interface displays an error message indicating what type of error has occurred. The Fig. 6 illustrates some of these errors.

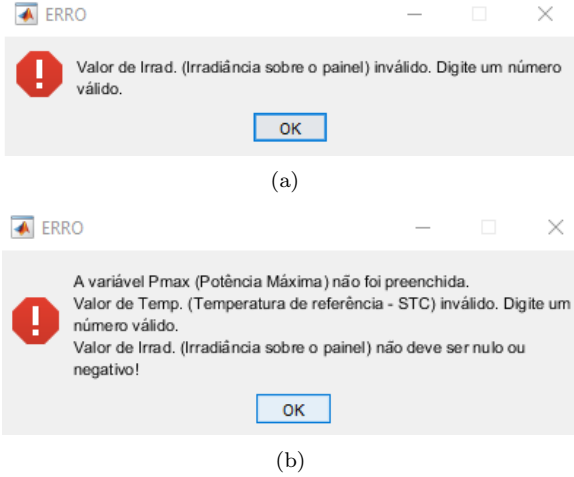


Figura 6: Some of the errors messages: (a) Invalid numbers; and (b) Multiple erros.

3.3 Case of Study

The students attending the workshop to fill the fields of the interface using the datasheet of a KC200GT from KYOCERA. By using the interface, the students could find n operations points of the PV module. This helped them to understand how the variation of the atmospheric parameters (irradiance and temperature) will affect the output power of a PV module.

Before handling the interface, a 30 minutes presentation was held. In this presentation, the lecturers showed the single-diode model of a PV cell and how the association of n cells, in series and/or in parallel, results in a PV module. The single-diode model was utilized because this is the most didactic and suitable for a introductory workshop.

The series resistance R_s and the parallel resistance R_p of the PV module, usually, are not provided by the manufactures in the datasheets. Thus, some papers present solutions for estimating those parameters (Villalva et al., 2009), (Gomes et al., 2017). However, the interface masks the estimation of R_s and R_p , calculating those parameters by itself.

Having filled all of the fields of the interface, including the operation range of analysis, the interface will plot the characteristics curves of the PV module modeled. As can be seen in Fig. 5, multiple operation points of irradiance can be plotted simultaneously. Using the interface, the

student can notice the behavior of a photovoltaic module without a deep knowledge about its modeling.

This also helps the simulation and design of a power converter built for PV systems. Having knowledge of the power source of a converter is fundamental on its design. Being the PV modules non-linear sources, to stipulate the operation range of the PV module (power source), allows a more precise project of the power converter.

Fig. 5 shows a variation of irradiance, but the the interface can also plots a variation of temperature. Thus, the interface can provide precise data about the operation point of a PV module, either for a range of irradiance or temperature.

4 Feedback and Outcomes

A satisfaction survey was made in the weeks following the Workshop. The two editions of the workshop had 33 attendees, showing that the Workshop had a good reach. The results of the survey are shown in Fig. 7, ranging from 1 (Very bad/unlikely) to 5 (Very good/likely). The eva-

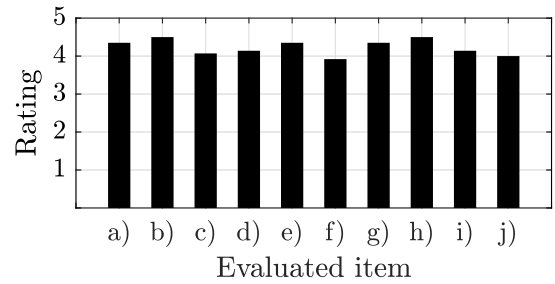


Figura 7: Feedback survey with ratings ranging from 1 to 5.

uated items are the following, as shown in Fig 7: a) Were the topics covered interesting and contributed to your training?; b) How do you classify the Manual?; c) How do you classify the methodology of the workshop?; e) What did you think of the Workshop duration?; f) What did you think of the registration fee?; g) How do you classify the Workshop publicity?; h) In general, how do you evaluate the Workshop?; i) Would you recommend this Workshop to a friend?; j) After completing the Workshop, how interested are you in volunteering for IEEE?; and k) After completing the Workshop, how interested are you in being a PELS/IAS volunteer? As can be noticed, most of the evaluated items had an approval rate superior to 4 (Good). The lowest evaluated item is the publicity, which the SBC plans to solve using physical advertisement (such as flyers around the university) in the next editions, not only Facebook® and email.

The SBC had their activities described in more details by Freitas et al (2017), including the



Figura 8: Volunteers and participants during the end of the 1st edition of the workshop.

presented Workshop.

The SBC believes that activities such as the workshop presented in this paper, having some educational tools as the GUI, can attract more volunteers, partners and participants in the following months. The GUI was a fundamental piece of the workshop with the intuitive interface and didactic approach helping the attendees of the workshop to understand what was presented.

5 Conclusions and Future Work

This paper has presented a successful workshop on photovoltaic systems. This workshop give to the students the opportunity to be introduced to PV system themes. The activity achieves some technical content still uncover in many electrical engineering formal education.

The use of a GUI as an educational tool was well received and notably reaffirmed by the feedback. The objective of the authors is to promote engagement among engineering students and enhance the teaching process on photovoltaic systems.

Future work to improve the GUI will continue to add content on other topics regarding photovoltaic systems engineering, such as grid-connection and design and analysis of power electronics converter related.

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