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Design of Simulation Tools for Teaching in Photovoltaic Energy Engineering †

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Abstract: Software tools are used to support the development of engineering projects in different fields, including the area of renewable energies (solar photovoltaic, thermal, wind, etc.). In the field of solar energy, there are commercial programs that allow sizing the installations and evaluating their performance. Some of the most representative are PVGIS, the Photovoltaic Geographical Information System, PVSYST, a tool designed by the Energy Group of the Institute of Environmental Sciences of the University of Genova, and Censol, developed by the Spanish Center for Solar Energy Studies. This paper describes different simulation tools developed at Alcalá University in order to teach photovoltaic energy engineering. A web application is compared to other tools, such as spreadsheets and applications in Matlab environment, developed by the authors. In all the cases, the tools are focused on learning project engineering.

Keywords: E-learning; solar engineering; software tools

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1. Introduction

Software tools are commonly used to support the development of engineering projects in very different fields. In particular, they are applied in the area of renewable energies (solar photovoltaic, thermal, wind, etc.), technologies that are expanding significantly over the past years.

In the field of solar energy, there are commercial programs that allow sizing the installations and evaluating their performance. Some of the most representative are: (1) the Photovoltaic Geographical Information System (PVGIS), developed by the European Commission, a web application that provides an inventory of cartographic basis of the solar energy resource and the evaluation of the generation of electricity from photovoltaic systems in Europe, Africa and southwester Asia. (2) PVSYST, a tool designed by the Energy Group of the Institute of Environmental Sciences of the University of Genova to develop photovoltaic installations that enables the study, simulation and analysis of data of photovoltaic systems. (3) Censol, developed by the Spanish Center for Solar Energy Studies (Censolar), a calculation tool to automatically perform the basic dimensioning of facilities, study and analysis of the yield of solar radiation [1].

In addition, it is very common to use spreadsheets or programs developed in languages such as Matlab, Python, Octave, etc. These applications are usually focused on the design phase of the installation, in which the basic characteristics of the installation are already known to some extent: location of the components, construction characteristics of the site, approximate layout of the installation wiring, etc. Furthermore, the aforementioned tools are designed to be used by trained designers, with theoretical and practical knowledge and with some experience in the sector.

All these tools are usually inefficient when performing the tasks of the preliminary project phase, in which it is essential to attain an approximate dimensioning of the installation within a short time and with enough precision. Besides, the aforementioned tools are used by engineers during their training period. In addition, simulators for solar installations are not designed with a didactic approach that would reinforce the theoretical concepts underlying the equations used.

2. Aims

The main objective of the work is to analyze the different options available as tools for designing solar energy projects focused on engineering learning, as well as to identify the main advantages and disadvantages of each alternative in terms of its effectiveness in the didactic field. Firstly it is shown the PVLEARNING project, developed in a web environment. The tool aids the engineer in the design of photovoltaic systems. In particular, it provides support to the following:

- Evaluation of the solar energy available at the selected site.
- Selection of photovoltaic and inverter (or inverters) modules.
- Configuration of the solar field (rows of modules in series and/or parallel) and of the inverter.
- Calculation of the installation yield.

A spreadsheet developed by the authors and a program in the Matlab environment have also been used for the same purpose. The article discusses the advantages and disadvantages of the different options, and their influence on the teaching/learning processes.

3. Development of the Software Tools

The tools developed at Alcalá University (Madrid, Spain) for the simulation of photovoltaic solar systems are described below.

3.1. PVLEARNING Web Environment

The PVLEARNING project has been developed in successive phases, as detailed below.

3.1.1. Development of a Model for Energy Production of Grid-Connected Photovoltaic Installations

An exhaustive literature search was carried out to find out the models used to date as a basis for the current simulation programs, and those described in ref. [2–4] were selected. Accordingly, a new model was developed, focused on the learning of project engineering while maintaining all the functionality and precision during its use in the design phase of the project. PVLEARNING calculates the energy generated by a photovoltaic system (E_{AC}) by means of the expression:

$$E_{AC} = P \cdot G_{aef} \cdot F_P \quad (1)$$

where P is the peak power of the photovoltaic generator, G_{aef} the value of the effective annual irradiation in the plane of the modules and F_P a factor that considers the losses of the system.

3.1.2. Development of the Source Code for the Simulation of Photovoltaic Systems

After obtaining the analytical expressions of the model, the software tool that constitutes the calculation core of PVLEARNING was made using Matlab. The program was thoroughly tested, and was compared with PVSYST, the tool most widely used for this purpose. The differences between the results obtained by PVLEARNING and those of PVSYST were lower than 2% for fixed systems and smaller than 5% in systems with solar tracking.

3.1.3. Development of the Graphical Interface for the Use of the Software in a Web Environment

After obtaining the core of the program and once it was debugged, the graphic interface was implemented for use in the Web. This interface was implemented with the PHP and Java Script languages. MySQL was utilized for the databases used by the application.

3.1.4. Start Up of the Developed Platform. Application for Improving the Teaching in Subjects of the Industrial Engineering Area of Alcalá University

Users of PVLEARNING can access to two different profiles or modalities (Figure 1). In the self-evaluation mode, they can create a project with all the functionality of the system, which provides the correct solution and compares it with that introduced by the user. If the comparison is favourable, the user becomes profile 2, project design modality.

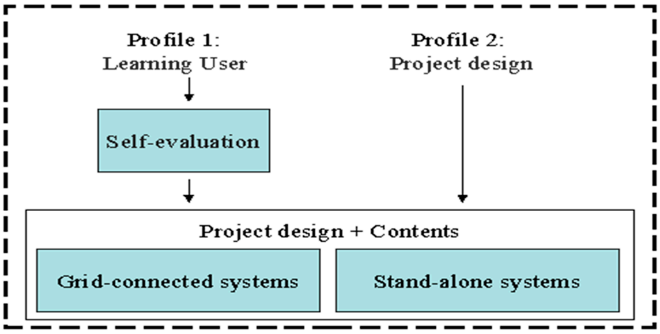
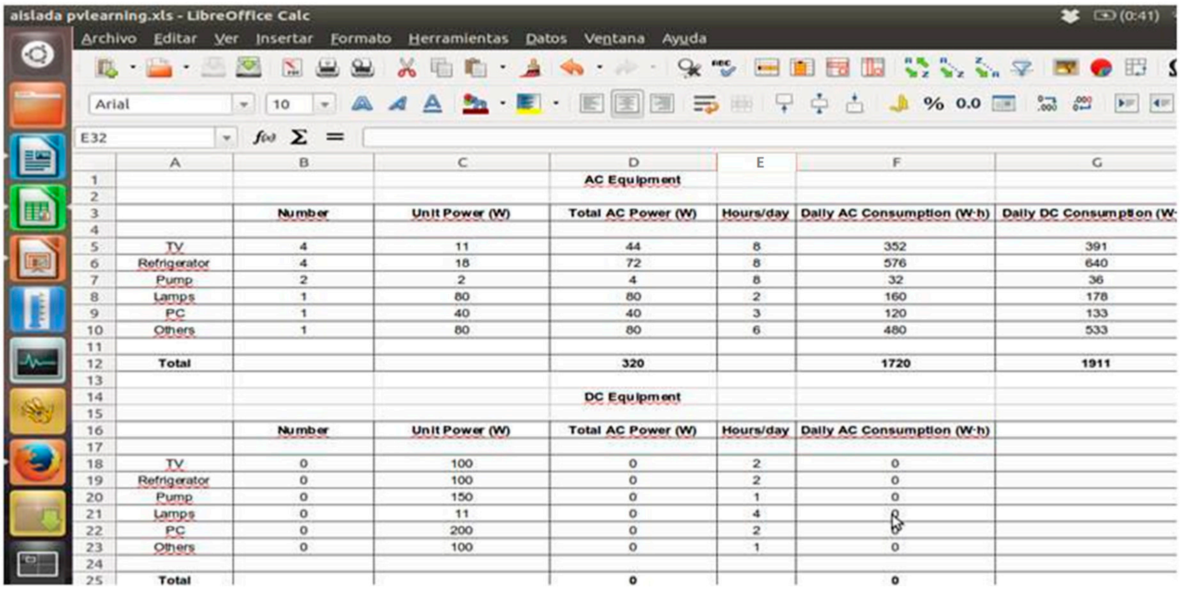


Figure 1. Simplified scheme of the structure of the PVLEARNING platform.

3.2. Simulation Tools in the Form of a Spreadsheet and in a Matlab Environment

The theoretical model for the simulation of photovoltaic installations has been implemented in Matlab, and a spreadsheet with the same equations has been developed (Figure 2).



	A	B	C	D	E	F	G
1				AC Equipment			
2							
3		Number	Unit Power (W)	Total AC Power (W)	Hours/day	Daily AC Consumption (W·h)	Daily DC Consumption (W·
4							
5	TV	4	11	44	8	352	391
6	Refrigerator	4	18	72	8	576	640
7	Pump	2	2	4	8	32	36
8	Lamps	1	80	80	2	160	178
9	PC	1	40	40	3	120	133
10	Others	1	80	80	6	480	533
11							
12	Total			320		1720	1911
13							
14				DC Equipment			
15							
16		Number	Unit Power (W)	Total AC Power (W)	Hours/day	Daily AC Consumption (W·h)	
17							
18	TV	0	100	0	2	0	
19	Refrigerator	0	100	0	2	0	
20	Pump	0	150	0	1	0	
21	Lamps	0	11	0	4	[illegible]	
22	PC	0	200	0	2	0	
23	Others	0	100	0	1	0	
24							
25	Total			0		0	

Figure 2. Tool developed for the simulation of photovoltaic isolated systems.

4. Results

The PVLEARNING website was used in undergraduate and postgraduate subjects in the Industrial Engineering Area of Alcalá University, on a sample of 90 students. The simulations were used to support the theoretical lessons, and served as a link between the theoretical contents and those related to the project-engineering design tasks. The students made the first contact with a design tool similar those used in professional jobs. All this results in increased effectiveness of the teaching-learning process and a greater motivation of the student when they focus on concepts with a high level of difficulty. Further, the students use PVLEARNING to perform evaluation tasks of the subject, autonomously, similar to the final year students. The results obtained were very positive. Comparing with former experience with the same subjects, a lower number of dropouts has been detected and a significant improvement in the quality of the evaluation works presented. This improvement can be attributed to the following factors related to the use of PVLEARNING:

- The tool acts as a link between the theoretical-academic contents and those related to the project-engineering design tasks. Thus, the use of ICT in the study allows reinforcing the concepts, emphasizing their practical use.
- There is an increase in student motivation when studying difficult concepts. This is a consequence of using a design tool similar to those you will use in your professional career.
- A higher level of participation in class was detected, owed to the increased student motivation.

With respect to PVLEARNING, the program in Matlab and the spreadsheet described above have the following disadvantages:

- Require the previous installation on the student's computer, which must also have an operating system compatible with Matlab or Microsoft Office/Libre Office/Open Office.
- The implementation of the self-evaluation modality is possible, albeit sending and recording the results is not automatic, it must be done in a "manual" manner by the students and the teacher. In the case of PVLEARNING, the website itself acts as a tool for collecting information.
- The incorporation of the theoretical concepts behind the equations of the model can be done both in Matlab environment and in a spreadsheet. However, the web environment allows a much more attractive visual integration, more intuitive, and easier to use.
- Both options do not allow direct student-teacher interaction, enabling the online alternative.

5. Conclusions

In this work, different tools for the design of solar energy projects have been shown and analyzed, all of them focused on engineering learning, and the main advantages and disadvantages of each choice have been identified in terms of its effectiveness in the didactic aspects. The PVLEARNING project is presented, created in a web environment, a spreadsheet and a Matlab program, the three of them implemented by the authors. In all cases, the tools act as a link between the theoretical contents and those related to the tasks of project design, reinforcing concepts and emphasizing their practical use. An increase in student motivation was observed, as a result of using a design tool similar to those utilized in professional jobs, and also a higher level of participation in class. In addition to practical features (no previous installation on the student's computer is required, nor having a compatible operating system), PVLEARNING allows integrating self-evaluating tools, data collection related to the learning process and the integration of theoretical contents in a much more attractive and intuitive way,

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Conflicts of Interest: The authors declare no conflict of interest.

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