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Exploring the usability of a remote laboratory for photovoltaic systems

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Abstract: In engineering, remote laboratories present a triple role: they provide to the students the necessary contact with real devices, introduce them in the use of new technologies and make possible that the students conduct lab classes when and where they want. In this paper we present a remote lab devoted to photovoltaic power. The experimental system consists of two photovoltaic panels connected to a variable load and illuminated by a variable luminary. It allows the students to obtain different characteristic curves. The user interface has been integrated in Moodle. The system access management is carried out by software developed by authors. A didactic valuation process has been carried out to establish the acceptation of the educational experience by the students and to identify underlying factors. The hardware and software developed for this remote lab are not specific, but reusable for other remote lab experiences besides the one presented here.

Keywords: Engineering education, Remote lab, Photovoltaic System, Lab class, Pedagogical analysis.

1. INTRODUCTION

Practical training is an unavoidable part of scientific and technical studies. These classes have traditionally been taught in the laboratory. Their physical realization has several advantages. Mainly, the students take contact with the devices that they will handle in their professional development. In addition, it allows them to learn their real behaviour. In the last years, remote laboratory projects have been proposed. The aim is to teach fundamental concepts in different engineering fields through the remote operation and to control specific experimental facilities. Different activities towards the development of virtual and remote laboratory systems, (Andúajr and Mateo 2012), (Gomes and Bogosyan 2009), are carried out by many academic institutions they cover several engineering fields ranging from electronics, (Sousa et al. 2010), (Andújar et al. 2011), to the automatic, (Santana et al. 2013). Focusing on photovoltaic systems, there are multiple papers about remote transmission systems to monitor them, (Bagnasco et al. 2012), (Naeem et al. 2011), among others.

Within the educational area, and focused on photovoltaic systems, virtual labs, (Drigas et al. 2005), are more extended than remote labs, (Thomsen et al. 2010), (Schauer et al. 2012), (Freeman et al. 2012), (Assante and Tronconi 2015). Among this last kind of labs, in (Thomsen et al. 2010) a photovoltaic remote system is presented as a part of another one which is composed of some other physical experiments. In addition, in (Schauer et al. 2012) authors propose the characterization of a solid state photovoltaic cell using several photovoltaic systems. In (Freeman et al. 2012) a remote experiment is presented based on photovoltaic panels which makes possible that the student turns on and off a number of light bulbs, adjusts the load voltage by the photovoltaic panel and follows the experiment evolution in real time via web-cam. Another experiment based on photovoltaic system is presented in (Assante and Tronconi 2015). However, in this case its remote access is still in development.

Regarding the learning planning, one of the first experiments proposed to the students in courses about photovoltaic energy is the determination of modules characteristic curves and the effect of the meteorological conditions on them.

In this paper, a remote experimental system is presented, constituted by two photovoltaic modules connected to a variable load and lighted by a variable focus. It allows the students to obtain different characteristic curves and compare them. For example: curves with several irradiations and curves corresponding to one and/or two modules connected in different ways (serial and parallel). In this case, the student is an active element of the class. He or she takes the data, analyses them and draws the corresponding conclusions.

Regarding technical issues, to develop the remote lab presented in this paper, the innovative instruments related bellow were designed. All of them will be explained in the corresponding section.

- The use of Arduino board to control a high power luminary. Arduino, (Arduino 2015), is an open-source platform used for building electronics projects. Arduino consists of both a physical

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programmable circuit board and an integrated development environment (a simplified version of C++) that runs on the computer.

- The use of Easy Java Simulation (EJS), (Esquembre 2015), to design the lab class experiment and its integration in a Learning Management System (LMS).
- The use of Augmented Reality (AR) techniques to improve the interface, (Mejías and Andújar 2012).
- The use of Modbus, (ModBus 2015), to unify the communications among all the components of the experimental system.
- The use of the Remote Access Service for Labs (SARLAB) as the system of access management. It is a communications software developed for this purpose.
- The use of a Raspberry Pi board (a low cost and small computer that plugs into a computer monitor or TV, and uses a standard keyboard and mouse), (RaspBerry Pi 2015) to optimize the energy consumption of the laboratory. This is not energized until a remote user wishes to use. Until then all its elements are off.
- Finally, a very important characteristic of the developed remote lab is that all hardware and software elements are open-source, so its setting-up and maintenance are low cost.

Within pedagogical framework, there are several papers in the Literature which have treated the analysis of usability of remote laboratories in University, (Casini et al. 2014), (Kulkarni and Jhunjhunwala 2013), (Tsiatsos et al. 2014). However, none of them have explored the dimensions underlying to the usability variable and its relation to the perception of usefulness by students. The identification of those factors in the design of remote labs will allow its acceptation by educative communities.

The paper is organized as follows: in section 2, the need for promoting the capabilities developed by the lab class in the Energy Engineering Degree is explained; in section 3, the designed lab class is presented and in section 4 the structure of the developed remote lab. In section 5, results of the analysis obtained are shown. In Section 6, the discussion of the usability is made. Finally, in section 7, some conclusions are drawn.

2. THE LAB-CLASS INTEGRATION IN THE SUBJECT

The behaviour of a photovoltaic panel is characterized by a curve which presents current versus voltage (V-I), Figure 1.

The remote lab is proposed as an instrument to improve the student knowledge of photovoltaic systems and, specifically, of the behaviour of the panels in real environmental conditions (mainly irradiance) when they are connected to other panels and to different loads as happens in the real world. In addition, the student increases their skills on connecting photovoltaic facilities, carrying out electrical measurements and analysing them. The proposed remote lab class is also carried out in classroom labs with the same objectives. However, the remote lab provides the ability to carry out the experiment whenever and wherever the student wants.

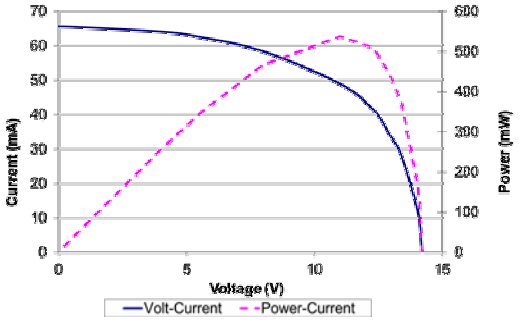

Figure 1. Photovoltaic module characteristic curve.

The lab class has been proposed to be conducted by the students enrolled in the Photovoltaic Solar Facilities. This is a compulsory subject, taught in the second course of the Energy Engineering Degree at the University of Huelva. The considered lab class is one of the first practical exercises proposed. In fact, the student must know the panel behaviour before boarding the photovoltaic facilities world.

Previously to make the proposed experiment, the student must know the photovoltaic panels and their theoretical behaviour. In addition, the teacher supplies to the student by means of the LMS a guide of the experiment.

3. LAB CLASS DEVELOPMENT

The developed user interface is shown in figure 2. It is composed of two parts. In the first one, in the top, the video image can be seen. It shows two photovoltaic panels lighted by a variable luminary, whose intensity is also shown by the camera image. However, the load presented in the image is not the actual one but it has been developed with AR technics as well as the panels connection in each case. Voltmeter and ammeter have also been included as AR elements in the user interface.

The second part of the user interface is constituted by the controls of the parameters that the users have to manipulate to conduct the remote lab class. They must regulate the luminary power (irradiance on the panels), item A in figure 2; load value, item B in figure 2; and panels connection, item C in figure 2.

Thus, for each light condition (irradiance condition) and each panels connection, students must change the load resistance value and taking notes of voltage and current in the load. They must keep all data in a datasheet to graph them as the lab class guide proposes: they must make one graph for each connection with all the curves corresponding to it (one for each light condition). These graphs will show to the students