Development of a compact and didactic solar energy kit using *Arduino*

João Costeira[1], Manuel Vieira[1], Abolfazl Hayati[2], João Gomes[2,] and Diogo Cabral[2]

[1] University of Minho, Portugal

[2] University of Gävle, Sweden

Abstract

When the sun rises, so does the key element that will shape the future of the world energy landscape. It is not an understatement to say that the solar energy industry is beginning to lead the path towards a sustainable future for all of us. However, the awareness of the potential of this amazing source of energy must begin from the most basic levels of education all the way to university. The scope of this paper is to display a new compact and didactic solar energy kit with the potential to replace current high cost and complex solar energy kits. These solutions are often too expensive and therefore unavailable for most of Europe's public schools. As such, an equipment was developed using an open-source platform called *Arduino* that will enable students to conduct practical experiments in a fast, effective and simple manner and thus allow students to acquire the proper expertise in areas like energy, electronics, and programming.

Keywords: Photovoltaic (PV) cells; Solar energy; Teaching kit; Active learning; Arduino

1. Introduction

The education of science and engineering plays a significant role in modern society, serving as a base for the current technological developments. Moreover, the increased demand for sustainable sources of energy, like solar or wind, must be side by side with a sustained educational policy that provides trustworthy tools and conditions for young students to develop their technical skills in such areas as well as increase their awareness of the existing green technologies. Integrating labs with lectures can also increase the so called-active learning with students via learning by doing experience (Sanders et al., 2017). Renewable energy technologies are experiencing a rapid growth, like solar photovoltaic with the recent reaching of the 300 GW milestone, and this is leading to a larger scale production and price reduction. Nonetheless, this rapid growth has exacerbated the problem of a serious shortage of skilled professionals, with experience in renewables (Jennings, 2009). Among the most important needs of the renewable energy industry are the initial training of scientists and engineers to design and develop new renewable energy systems (Jennings, 2009). Additionally, studies have identified the lack of undergraduate studies in renewable energy technologies, the unsatisfactory, encyclopedic rather than a systematic approach to teaching renewable energy sources at engineering faculties (Keramitsoglou and Kiriaki, 2016). As such, the improvement of the current solar energy equipment used in schools and universities is particularly sought after, especially if this improvement culminates with an increased technical skill obtained.

One of the main objectives for the construction of the photovoltaic (PV) solar energy teaching kit, the so-called CompactSun (Costeira, 2017), is to allow students to perform quality experiments in reduced space and in a faster manner. In fact, schools often do not have laboratory spaces and small classrooms by nature, are used as test benches. Compact systems can be built by reducing the number of components and materials used in the experiments and by improving their portability. In this context, and given that this kit was developed to be used mainly by secondary school students in a classroom context, it is crucial that the kit can be easily used without jeopardizing the learning objectives.

Taking into consideration that the main purpose of the development of this equipment is to provide students with learning by doing experience, we chose to use a hardware and software tool called "Arduino" (Arduino, 2018). Arduino is an electronic open-source platform and is widely used for various projects in the areas of electronics and robotics.

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Among the several advantages of Arduino are the following:

- Reduced price of its components;
- Transversally of your software, operating in the various operating systems;
- Simple programming environment;
- Open-Source Software;
- Open-Source Hardware.

The development of the CompactSun was driven by the increasing need to raise awareness near the next generations of students for the environmental challenges and provide the initial tools to the future solar energy engineers and scientists. The most advanced solar energy kits are often too expensive for most of the public schools, which are often obligated to rely on lower quality and cheaper didactic kits that aren't capable of helping students to meet their learning needs and don't stimulate the students to pursue a solar engineering career.

The main aim is to conduct practical experiments in a fast, effective and simple manner and thus allow students to acquire the proper expertise in areas like energy, electronics and programming. Moreover, such product should be affordable for the wide range of secondary schools throughout the world. As such, a reliable and innovative solar learning equipment was designed to help students to develop not only their energy skills but also their programming and engineering capabilities.

2. Methods

In order to verify the full functionality of the CompactSun prototype, two experiments were conducted. For both experiments, a 50W halogen lamp was used as a light source.

Experiment 1: Association of series connected photovoltaic

A photovoltaic system can be installed on the roof of a house in order to convert solar energy into electricity and help meet the energy needs of a particular family. The power of a cell, module or photovoltaic panel is measured in Watts (W), is calculated by the product between the voltage (V) and the current (I) it produces. In order to ensure that the system functions properly, it is necessary to find the correct balance between voltage and current. For this purpose, the PV cells or modules can be connected in series, in parallel or with a mixed configuration depending on the needs of the system to be fed. Students should discover through this experiment the effect on the voltage and current of the system of the connection of connected cells in series.

The solar cells used in these experiments each had 0.8 W power with 5 V Open Circuit Voltage (V_{OC}) and 160 mA Short Circuit Current (I_{SC}). The dimension of each cell was 80x80x3 mm. Using the photovoltaic solar photovoltaic prototype kit, students are asked to measure open circuit voltages and short-circuit currents for each of the three 0.8 W cells individually and record the values. They should then be series connected, the first cell to the second cell and then associate the third cell in series with the previous cells, see figure 1.

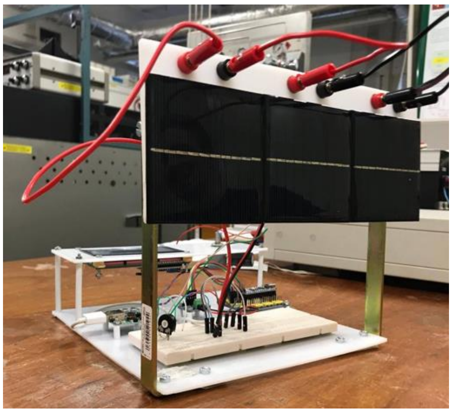

Fig. 1: Set up for experiment 1 – Association of series connected photovoltaic cells

Experiment 2: Current-Voltage (IV) characteristic curve of a photovoltaic cell.

If no load (for example an electric resistance) is connected to the photovoltaic cell under illumination, an open circuit voltage will be obtained but no current flow will occur. If the terminals of the photovoltaic solar cell are connected to one another (short-circuit condition) a very high current, the so-called short-circuit will be produced, but with a zero voltage. In either case, no power is produced. However, if a load with variable resistance is added it is possible to produce the characteristic curve of the PV cell. The objective of this experiment is to understand the influence of the variation of the load resistance on the voltage and current values of the photovoltaic cell.

In this experiment the photovoltaic solar energy teaching kit integrates only one cell, having 4.5 W power with 6 V Open Circuit Voltage (V_{OC}) and 750 mA Short Circuit Current (I_{SC}). The dimension of the cell was 165x165x3 mm. The photovoltaic cell was exposed to the action of a light source emitted by a 50 W halogen lamp. Figure 2 shows the prototype of the photovoltaic solar energy teaching kit with cell a) integrated into the system. Furthermore, a load (100 Ω potentiometer) was added to the system. In order to obtain the characteristic IV curve, the student must vary the load resistance of the system by using a potentiometer.

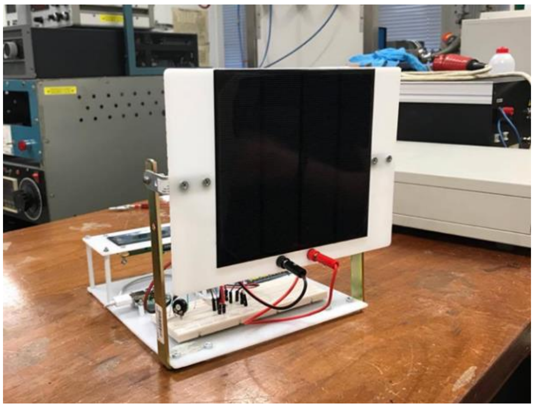

Fig. 2: Set up for experiment 2 – Current-Voltage (IV) characteristic curve of a photovoltaic cell

3. Results and discussion

The first task was to measure Voltage (V) and the Current (I) of each of the 3 solar cells individually. The results are presented in Tab. 1. Next, each cell was gradually connected to the other and the same parameters measured. Cell 1 individually, cell 1 + cell 2 and finally cell 1 + cell 2 + cell 3. The results are presented in table 2.

Tab. 1: Voltage and Current of the three 0.8W solar cells individually

	Cell 1	Cell 2	Cell 3
Voltage (V)	5.28	5.32	5.26
Current (mA)	152.1	155.2	153.6

Tab. 2: Series connection of the three solar cells

	Cell 1	Cell 1 + Cell 2	Cell 1 + Cell 2+ Cell 3
Voltage (V)	5.28	10.58	15.84
Current(mA)	152.1	154.7	153.4

After analyzing the experimental results, one can realize that the open circuit voltages of the individual cells correspond approximately to the open circuit voltage value supplied by the manufacturer (5 V). By associating the electrically coupled cells in series, it would be expected that the open circuit voltage of the system would be equal to the sum of the individual voltages of each cell. This assumption was successfully tested, as can be seen from the analysis of table 2.

Regarding the short-circuit current of the individual cells; it was also found that the values obtained are very close to the values reported by the manufacturer (160 mA). On the other hand, it is also observed that after the series connection has been made, the short-circuit current of the system practically remains unchanged. However, it should be noted that the small differences recorded in the short-circuit current values occur because they are located at slightly different distances from the light source. In fact, the central cell is slightly closer to the light source than the remaining two that are located at the end of the system, as can be seen in figure 1. This behaviour asserts that the distance and the angle of incidence of the light on a collecting surface are directly related to the number of photons that impinge on that surface and, consequently, capable of transmitting the sufficient energy differently to the electrons to generate electric current

In the second experiment, the photovoltaic solar energy teaching kit included only one cell. The photovoltaic cell was exposed to the action of a light source emitted by a 50 W halogen lamp, see figure 2. The resistance of the load was varied from the minimum to the maximum resistance and the values of voltage, current and resistance of the system displayed by the Liquid Crystal Display (LCD) were registered, see table 3. The values obtained were used to create the characteristic current-voltage (IV) curve of the cell, see Fig 3.

Tab. 3: Voltage, current and resistance registered in the experiment 2 set-up

Turns (in the potentiometer)	Voltage (V)	Current (mA)	Resistance (Ω)
Minimum load	0.08	66.7	1.2
1	0.72	66.2	10.9
2	1.55	65.7	23.6
3	2.09	65.3	32.0
4	2.59	61.5	42.1
5	3.06	59.8	51.2
6	3.57	57.4	62.2
7	4.06	56.4	72.0
8	4.49	55.3	83.5
9	4.87	53.8	90.5
10	4.93	48.7	101.2

According to figure 3, the IV curve produced with the experimental results is similar to the conventional IV curve of a solar cell thereby proving the functionality of the system. Plus, this practical experiment can easily be performed by untrained students with minimal guidance within 15-30 min. This is possible because the setup is already made and the results appear in the LCD automatically thus allowing a significant reduction in time. The IV curve experience is one of the most important tasks for those who want to learn the basics of electronics within the solar energy context. To reap the benefits of this task, one must keep the duration of the experiment below 30 min and avoid distracting deviations such as wiring. The IV curve experiment requires minimum wiring from the student, if the setup is previously prepared by the teacher, and therefore it can be completed faster.

It should be emphasized that the final price of the developed product was only around 75 Euros. For information about each component, please refer to (Costeira, 2017). This aspect is extremely important as it makes this system extremely competitive against similar products on the market and therefore endowing it with a high commercial potential as it can be widely purchased and used by hundreds of national and foreign high schools.

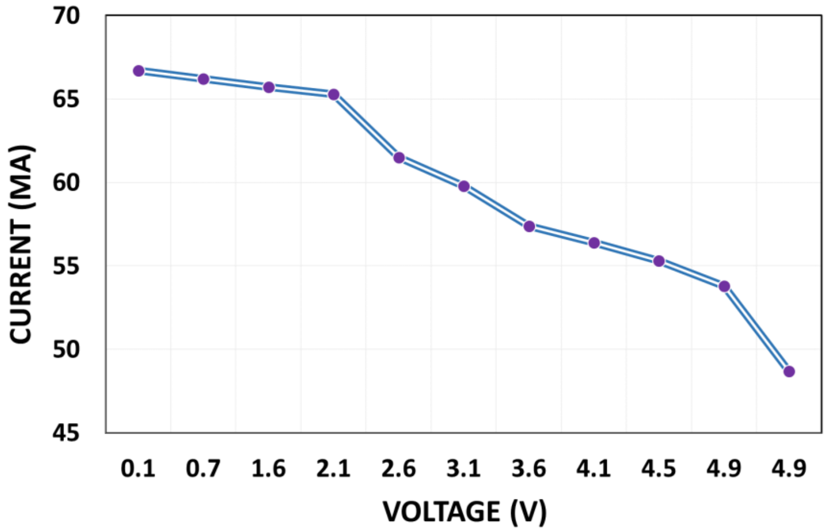

Fig. 3: IV characteristic curve of a 4.5W solar cell

4. Conclusions

The results obtained from the practical experiments conducted to certify the functionality of the kit and its potential to significantly increase the quality of solar energy education throughout the various levels of education all over the world. Furthermore, given the fact it is a low-cost equipment it can be purchased even by schools in the so-called "developing countries" and thus provide valuable conditions for students to develop their engineering acumen. In addition, the setup of the experiments allows a significant reduction in time required to perform them, when compared to experiments undertaken with conventional products. The CompactSun displays great versatility and allows students to perform distinct experiments with varying degrees of difficulty. As such, it is possible and recommends for maximum learning that the setup is built completely by the student, including programming and connections. This option, however, comes with the caveat that the duration of the experiment will increase with the rising difficulty. Notwithstanding, great benefits are obtained by the students who perform the experiments such as the ones described in this paper.

The time has come to provide the future generation of scientists and engineers with proper tools that fit their increasing potential. Additional improvements in design and robustness of the *CompactSun* are required to guarantee its durability and ensure reliable interest by the students.

5. References

Arduino. (2018, September 2). What is Arduino? Available at: https://www.arduino.cc/en/Guide/Introduction#.

Costeira, J. (2017). Desenvolvimento de um kit didático de energia solar fotovoltaica. [Development of a photovoltaic solar energy teaching kit], Master thesis (In Portuguese), University of Minho, Portugal. http://hdl.handle.net/1822/54825

Jennings, P., (2009). New directions in renewable energy education. *Renewable Energy*, 34(2), 435–439. https://doi.org/10.1016/j.renene.2008.05.005.

Keramitsoglou, Kiriaki, M., (2016). Exploring adolescents' knowledge, perceptions and attitudes towards Renewable Energy Sources: A colour choice approach. *Renewable and Sustainable Energy Reviews*, *59*, 1159–1169. https://doi.org/10.1016/j.rser.2015.12.047.

Sanders, K., Boustedt, J., Eckerdal, A., McCartney, R., & Zander, C. (2017, August). Folk pedagogy: Nobody doesn't like active learning. In *Proceedings of the 2017 ACM Conference on International Computing Education Research* (pp. 145-154). ACM. DOI: 10.1145/3105726.3106192.