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Teaching solar energy harvesting based on an educational solar cell, information technologies and basic electronics

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Abstract

Harvesting energy and photovoltaic effect was learned using a basic electronic circuit and an educational solar cell. Teaching and understanding concepts related with physics phenomena, semiconductor theory, electronics circuits and mathematical analysis is not a simple issue since soften students think those are very difficult by nature. The idea was move the students in the way to put hads on, it means built some cheap tools to understand the process involved in a solar cell to perform energy harvesting from Sun. Pothovoltaic effect is the concept behind the solar cell performance. Students were able to discover that around this concept there are important science and technological topics related; also they realize the importance of mathematics in technological development and the creation of new devices or applications. During the construction of low cost technological tool, students discovered for themselves, how and why the climate impact positively or negatively on the performance of harvesting energy from the sun through a solar cell. Interaction between electromagnetic energy and matter was understood and the way that scientific and technological knowledge can be used to develop low cost pedagogical tools to improve teaching – learning process.

Teaching – learning process, energy harvesting, Irradiance level

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Introduction

For students of Engineering Information Technology Physics is not only difficult but also stranger topic is opposite to their field of knowledge pole. They do not believe it has anything to do because the academic approach has not allowed sensitize young IT students about the importance of physical concepts and mathematical theories related to them. Electronics is a branch of physics; the vast majority of IT currently uses electronic devices. It is very familiar to them using wireless communication networks, in college, at home, in shopping malls, entertainment centers, and street and in some cases their workplaces; but it is not as familiar with the concept electromagnetic wave, wavelength, angular frequency, refractive index, and so on.

If something as used by them, as wireless telecommunications networks do not relate to physics, is even more the case of harvesting solar energy by means of a cell. Physics is behind the conversion of solar energy into electrical energy and how you can take advantage of. It is also currently widespread use of renewable energy, even is already common to see solar cells in public telephones, and almost public domain, which are used to power electronic devices, but what about the operation of the cell, and that learning that it can serve the student iT? It's an interesting question to answer, but especially to arouse interest in young people to learn the concept of energy harvesting, because the same can be done with the energy that sends a wireless network using a rectenna. The entire process of generating electricity from energy harvesting is defined in three steps, Fig. 1.

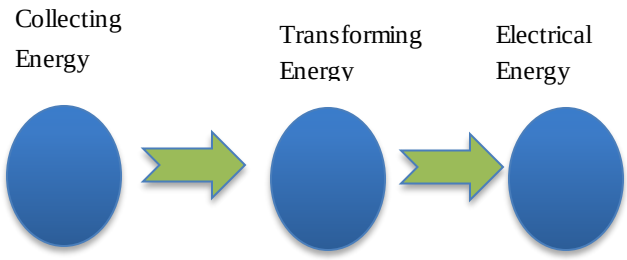

Figure 1 Steps to generate electrical energy from harvesting

What is interesting is how from this simple scheme, you can go analyzing the complexity behind each step, convincing the student IT with the knowledge gained and the needed acquire can understand the process of transformation energy and the importance related to renewable energy, sustainable technological development, and commitment as a technologist, but more like human being has with the planet earth. In the first step, a transducer collects energy. For almost all activities undertaken by most humans, they need electricity, so that the generation and distrubición of the same has to be very efficient. This has become one of the main challenges to overcome. It is necessary to employ generation techniques that are friendly to the environment, is the case of renewable energy or clean energy. For this reason it is necessary that any technologist knows the importance of them and the need to use them, but also how they work some of them, to have the judgment of discrimination in employment as appropriate.

Technologists and Scientists are continuously aiming their activities to find new sources of clean energy; Two of them are the well know solar energy harvesting using solar cells (Salinas, Estrada, & Luna, Energía Limpia con Celdas Solares, 2012) (Sze & Kowk, 2007). Other one of new energy sources is Space Solar Power (SSP) according with according to the scientific and technological community is the promise sustainable energy source for mankind in near future.

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This one works under the Wireless Power Transmission Concept (WPT) (Agbinya, 2016). A transducer is a device that converts one type of energy into another. In the case of solar energy, the transducer is the solar cell, which is a transducer device that converts sunlight into electricity. Rectenna is a transducer device that converts electromagnetic energy into electrical energy.

Solar cell works under the physical phenomenon called Photovoltaic Effect. The solar cells convert electromagnetic energy into electrical energy, generating an electric potential (voltage) between its terminals. This process of energy conversion is based on the photovoltaic effect (Rappaport, 1959), which is why they are also known as photovoltaic devices. Albert Einstein in 1905 (Einstein, 1905) and Walter H. Schottky in 1930 gave a deep understanding of the scientific principles of the interaction of light with materials and physics of semiconductors, respectively.

In both cases mentioned above, is implicit electromagnetic energy concept that IT student if related to their field of knowledge. However it may not be demasido Emphasize the importance of getting to know the behavior of this energy and its interaction with matter. This knowledge is the immediate relationship of wireless technology with physics as a result. So it is necessary for learning techniques that are effective and attractive to students, one of them is do it yourself (DIY) employed.

It must be clear that the objective is that the student understands what you are trying to learn, so it can make value judgments about the results they are getting. If the pretension is that students learn simple, imples things, teaching can also systematize simply, identifying tasks that teachers should routinely apply.

If it is to develop skills and more structured and transversal competences, it is necessary to apply techniques to meet the objective. There are several examples on the subject reported in the literature, however many of them are focused on virtual labs, software and physical laboratories with open source hardware (Salinas, Angel, Luna, & González, 2014) (Salinas, Estrada, Luna, & González, Developing Mathematical Literacy, Based on Elemental Software and Academic Tools Development, 2013). The initiative to use solar cell for teaching physical concepts behind energy harvesting through any device, emerged from previous work that was done in the institution. This paper presents a Solarimetric station was built based on hardware and open source software (Salinas, P.J., Estrada, & Luna, 2013).

Based on own and others experience one hyphotesis can be enunced:

Deep understanding abput physical concepts behind energy harvesting can be getting based on the experimentation.

The academic solar cell was used to work as a pyranometer, which is the device used to get Irradiance level information.

Methodology

The first step is to teach how a solar cell is, and how it works in general as a transductor, Fig. 2.

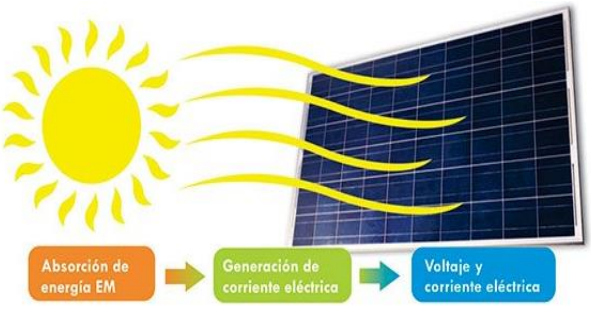

Figure 2 General view of how a solar cell work

The parameter that qualifies how efficient the solar cell works as a transducer is the Power Conversion Efficieny (PCE) (Sze & Kowk, 2007). It indicates the percentage of the solar energy was converted to electrical energy. Is important to clarify to the students that in every energy conversion there are losses, not all energy is converted in the one is desired (Goswami & Keith, 2007). In the field of solar cells not al Electromagnetic Energy that incides over its surface is converted into electrical energy, due to internal and external factors. If the losses are seen as resistance, valid approximation, TI student understand the general idea. Solar Cell I – V curve, Fig. 3.

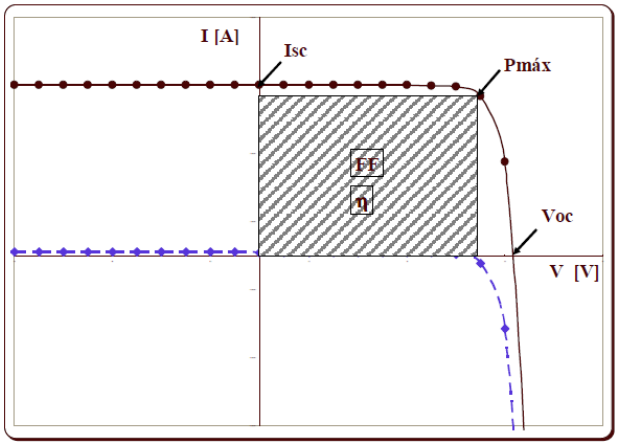

Figure 3 Learning solar cells PCE concept base on electrical circuit behavior

The maximum power point (Vm, Im) is the one where the "resistence" is low and the conversion is higher. A valid analogy is the Antenna behaviour: resonance frequency (Balannis). A calculus worksheet was used as TIC tool to teach and understand the antenna maximum transferring point, Fig. 4 (UTEZ, 2014). The relationship between PCE of a solar cell and antenna resonance frequency is done base on the behaviour of a simple electrical circuit, and the parameter of resistence. Because resistence si all that is opposing to the flow of current or all things opposing to energy conversion.

Pm point is therefore the one where solar cell is converting most efficiently the solar energy.

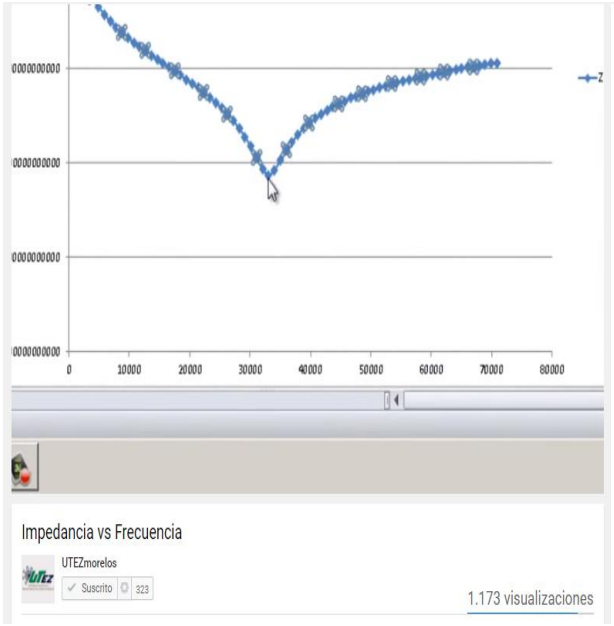

Figure 4 Maximum energy transfer: antenna resonance frequency

Figure of merits of a solar cells are the open voltage circuit (V_{OC}) and short circuit density current (J_{SC}) (Salinas, P.J., Estrada, & Luna, 2013):

$$V_{OC} = \frac{nkT}{q} * (ln\frac{I_L}{I_0} + 1) \quad (1)$$

$$J_{SC} = J + J_0(e^{\frac{q(V)}{nkT}} - 1) \quad (2)$$

And the equation including resistance effects, is (Sze & Kowk, 2007):

$$J = J_L - J_0\left(e^{\frac{q(V-IR_S}{nkT}} - 1\right) + \frac{V-IR_S}{R_{Shunt}} \quad (3)$$

It means the three basic electrical parameters of simple electrical circuits, are called to understand losses ar solar cell and the relationship of electrical resistance and PCE.

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Therefore electrical resistance is not the only parameter that affects the PCE level. First measurements of V_{OC}, J_{SC} and Pm, the educational solar panel and a multimeter that can record the data automatically were used, Fig. 5. Students record the behaviour of the solar irradiation during the day for one week, panel was angled according with latitude and altitude coordinates of the campus.

Once this concept of losses is understood the next step is to teach it under basic physics of semiconductor devices, Fig. 6. Electromagnetic energy could be view as a wave and also as a particle, but this is a concept that needs special treatment, for the purpose of this job with the photon concept is enough.

Photon has energy depending on its wavelength (Sze & Kowk, 2007). Photon Energy (hf) needs to be higher than the electrical band gap (Eg) to electrons jump form the valence to the conduction band.

Figure 5 Measurement of electrical figure of merit of solar energy conversion

Once it is happened electron – hole (e – h) pairs are created, and as a consequence they are going to be separared by an internal electrical field.

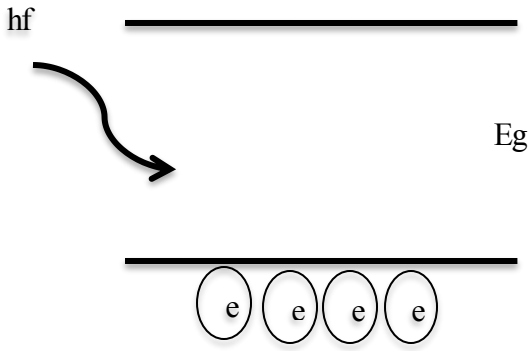

Figure 6 Concept of resistance applied to photon energy and semiconductor band gap interaction

Two important things: not all the incident photons generated e – h pairs, and since semiconductor is no an ideal electrical conductor not all separated e – h pairs are going to be collected at solar cells terminals. It means there are some resistance to energy conversion and there are losses to forbid the 100 % efficient.

Results

As part of this job, students got a deep understanding of physics behind the energy harvesting form solar cells. TI students also got abilities about technical equipment use, and develop adademic competences as research skills, discrimination about their knowledge sources, autocritical sense, autonomous work, and so on. Some others academic tools were developed as part of the work, these ones are based on calculus worksheet (videos utez), Fig. 7, Fig. 8.

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Physical concepts behind the technological tools are well understood using simple and free tools. Low budget universities need to look for options to develop complex competences in the students.

Also a correlation analysis and a low cost solarimetric station were constructed (Salinas, P.J., Estrada, & Luna, 2013). The value added of this work is the use of open source of software and hardware, and the web site view, Fig. 9

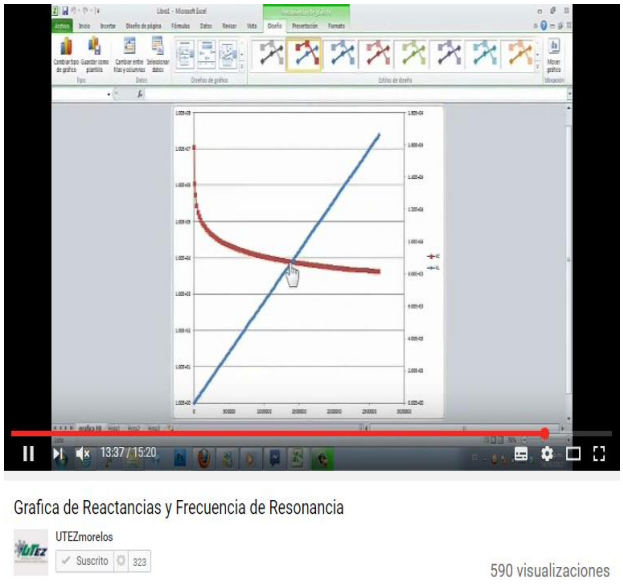

Figure 7 Concept of resistance applied to photon energy and semiconductor band gap interaction

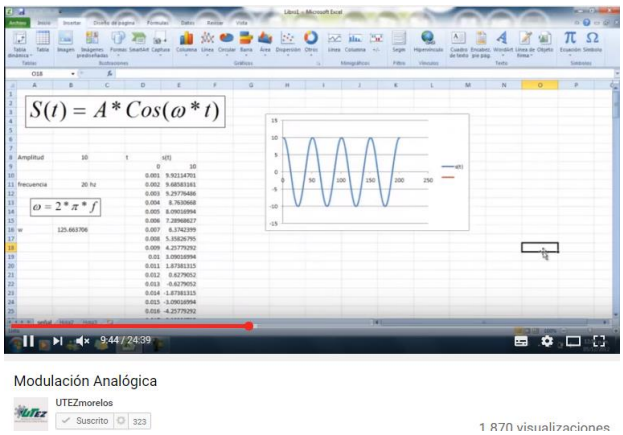

Figure 8 Web view of UTEZ solarimetric station

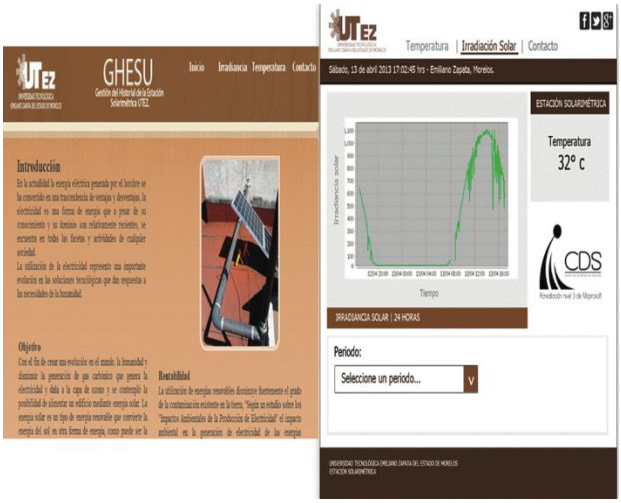

Figure 9 Web view of UTEZ solarimetric station

Conclusions

DIY techniques are efficient and useful as an aid in the teaching process - learning. The student engages in the development of a prototype, from conception of the idea, design or experiments, to the analysis of the final behaves. It understand the elements that compose it, and the role of each of them acquires the culture of the trial, questioning, trying to answer for itself the questions that arise in each of the activities.

Another skill that develops the student learning under this scheme is the researcher, is he who seeks information sources on the subject, aquiriendo with this judgment of choice, learns to discriminate which of these sources actually provide scientific information, supported with solid theoretical arguments, and which does not provide the necessary knowledge. Students learn to integrate knowledge acquired in the classroom, learn to relate topics and give importance to basic science.

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No still sees physics as a matter totally alien to their discipline of knowledge rather sees it as a theoretical support to support the ideas that acquires. In the case of mathematics is a similar process, the student begins to understand the power of this tool, and the great usefulness, not only in scientific, but also in the technological aspect. Physics and Mathematics, in this case, interacting playing together for the development of technology, resulting in the world, as we know it today.

It is an academic completely obtained under this scenario (DIY) as in the development of technological prototype or any kind of prototype, they are getting valuable work products, such as manuals, educational tools, design practices and equipment teaching in general that it can be used in subjects related to the subject.

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