European Association for the
Development of Renewable Energies,
Environment and Power Quality (EA4EPQ)

International Conference on Renewable Energies and Power Quality
(ICREPQ'11)
Las Palmas de Gran Canaria (Spain), 13th to 15th April, 2011

Simulation and Modeling of Systems in Engineering Education for the Sustainability. The Renewable Energy Case

Edmundo Guerra, Yolanda Bolea and Antoni Grau

Automatic Control Dept, Technical University of Catalonia, UPC, Barcelona, Spain
{yolanda.bolea, antoni.grau}@upc.edu

Abstract. In this paper we discuss about the use of computer simulations for sustainable systems. We propose laboratory practices for those subjects taught in the Engineering degrees that use systems or plants in their laboratories. The proposal is to use renewable energy systems for those laboratories. The interest in simulation of this kind of systems is focused to forecast their behavior in order to control and actuate over them wasting the less natural resources as possible. In this paper, the use of a didactic material for laboratory practices is explained. This pedagogical resource is published in a web platform (http://model.upc.edu) where the student can find laboratory practices, the instructor explanations and the software to develop new dynamical models. We have the strong belief that undergraduate students must receive an Education for the Sustainability independently of their career together and transversally with the basic and specifically concepts of the own subject.

Key words

Mathematical Models, Sustainability, Renewable Energy, Simulation, Education.

1. Introduction

In the last years society has become aware of that the pattern of current development affects our Planet in a noxious way. The wrong and excessive use of the natural resources, the group of substantial changes in the environment (deforestation, natural disasters, climatic, pollution, lack of water...) has generated the environmental problem that all the countries of the world are living, especially the industrialized ones. Particularly, in the Mediterranean region the climate change effect will be the decrease of water supply, causing a higher health risk and a decrease of hydroelectric energy generation. In order to not increase the use of nuclear energy generation neither the primary energy production coming from burning fossil fuels, there is the necessity of shifting to the generation of renewable energy to help meet increased energy needs. Education and Training play an important role in the sustainable production of renewable energy (solar, wind, tides, geothermal, biomass...) as well as in a rational use of this energy (consumption reduction, effective energy transport, efficient grid system...).

The United Nations Decade of Education for Sustainable Development, declared from January 2005 to December 2014, demands a concerted effort to expand environmental education around the world. High schools are places where students and teachers share knowledge, learn skills, and shape values. Rarely, industrial technology is at the focus of the classic case studies used in environmental engineering ethics courses and textbooks. That makes sometimes difficult exciting and motivating technical engineering students to study and discuss these cases.

Besides, in our modern society, distance education has become a viable solution for students who require more flexible, accessible, and adaptive teaching systems, without spatial and temporal restrictions [1], [2]. In the past, the interaction methods for distance education were limited to the telephone, postal mail, or fax. Today's new information technologies provide alternative tools for improving teacher-student interaction, two of which can be pointed to as the most capable and reliable for distance education. These tools are hypermedia systems as a new way of arranging information and wide-area communication networks (i.e., the Internet) for information support [3]. Although these tools are sufficient for constructing support systems for subjects without a strong practical component, teaching of systems' modeling or other subjects with strong experimental content requires a new element. This new element must allow students to apply the knowledge acquired in a way that goes beyond the traditional laboratory with the presence of students, which requires the presence of students as well as an instructor. If the laboratory environment is to be transferred to distance education, the element required to put simulation and modeling concepts into practice is the virtual laboratory [4][5][6].

This article describes the experience in the Automatic Control Dept at the Technical University of Catalonia (UPC) in teaching "Simulation and Modeling" of renewable energy systems subjects that use dynamic and interactive simulations in a stand-alone or Web-based environment. This innovative university training has as main objective to transmit theoretical concepts, skills and attitudes in order to the students take into account the sustainability and greening solutions (energy saving, efficiency improving of energy use, CO_2 emission reduction, and recycling and life cycle assessment) as future professionals in Engineering.

2. Modeling and Control of Systems for the Sustainability

In fact, the application domains of renewable energy systems provide many opportunities and challenges for the technologies of modeling and control. There are different possibilities to connect modeling practices with solar and eolic energy production with the aim of finding better ways towards sustainability. For this purpose several case-studies in environmental renewable energy systems are proposed and used for training in different technical degrees (Automatic Control Engineering, Chemical Engineering, Industrial and Electrical Engineering, etc.). The main objectives of renewable energy systems modeling are the prediction, simulation and regulation of energy production, transportation and management. In this work we explain several case-studies to be applied in the education and training about solar energy production and its use in different real life applications.

The examples and case-studies about renewable energies and related environmental issues, proposed in this article, should be included in engineering curricula as an innovative educational methodology adapted to the sustainable requirements of new social and industrial challenges for engineers.

The article is organized as follows. First, the inherent relationship between the sustainable systems and the modeling and control of systems in the actual world is explained. Second, the educational MODEL web is briefly introduced. This pedagogical resource leads to the implementation of virtual laboratory practices of sustainable systems simulation and modeling based on a real case study, and one of these models is described. *Easy Java Simulations* is the tool that will be used to program the model and the views for the simulation. Finally, the didactic methodology used for the laboratory is explained, analyzing the tasks for the faculty as well as for the students.

3. The Web as a Pedagogical Resource

The fact that students use a virtual laboratory does not suppose that the laboratory practices have to be invented, and the idea is just the opposite: we propose the use of practices based on real cases. This can stimulate students in their practices and increment their interest in environmental applications in order to aware them that environment and engineering are closely related. The role of these students in the professional world will be decisive for the preservation of the natural resources.

The STEP project (Sustainability, Technology and Excellence Program at the Technical University of Catalonia UPC) has as its principal objective to ensure the existence of 'the sustainability and the social commitment' competence in the curricula of all the engineers. The institution support in this kind of activities is very welcome and encourages teaching staff in developing such activities.

Figure 1. Main page of MODEL website.

The authors have developed an innovative didactic resource: the MODEL web (http://model.upc.edu). This web, Fig.1, is a compilation of sustainable modeling education resources, specifically a virtual laboratory. In this webpage a collection of pedagogical resources in Dynamic Systems (System Theory) are presented. These resources are intended to analyze and predict some events in our World in order to understand them in their whole complexity. The resources are multidisciplinary and they will give us a systemic vision. The modeling and simulation of different systems that can be found in this page will help to understand the behavior and evolution of our society: ecology, human behavior, health, economy, biology, engineering, chemistry, history, politics, journalism, sociology, psychology, among others. By these applications, faculty can teach the basic concepts and fundamentals of the simulation and modeling integrating the sustainability in a transversal way. Our society is immersed in a myriad of systems that describe the World complexity and the systemic reality of the life. Therefore, the parts and the components of things must be analyzed in depth but it is also necessary to assembly these parts to understand how they interact to make up a single entity, this is what we understand as a system.

The models are oriented to be used in education (at university level) as well as in research. We have focused our attention in remarking an undeniable fact that must be taken into account transversally in all the disciplines: ‘Sustainability’. This website is continuously updated and new models are added, accepting external proposals.

The virtual laboratory is made up of models in the following typology (see Fig. 2 as a sample): 1) Aquatic systems; 2) Water management; 3) Human and social development; 4) Sustainable environments and populations; 5) Greenhouse gases; 6) Renewable energies. Specifically, for this course of Dynamic Systems, the focus of interest is the renewable energies [8] [9] [10]. Next, as an example one of the models published in the web is described: “Sultana Grape Solar Dryer” [7]. The laboratory practice describes the functioning of this solar plant. The representation of the system is done by an ordinary differential equation and an algebraic equation:

$$
\begin{aligned}
&MR = \frac{M}{M_0} a \exp(-k_0 t) + b \exp(-k_1 t) \\
&T = -15.8V^2 + 25.1V + 30.3 \\
&\text{where :} \\
&a = 0.336 - 0.004T \\
&k0 = 7.703 - 8.717\ln(V) \\
&b = 0.806V^{-0.039} \\
&k1 = -0.141 + 0.048\ln(T)
\end{aligned}
\qquad (1)
$$

The description of the solar plant and the practice statement is published in the web, see Fig. 2. The block diagram with the space-state/input/output variables is shown in the Fig. 3. Next, this model and its variables are described.

This software is prepared to simulate the thin layer solar drying for Sultana grapes using an indirect forced convection solar dryer under ecological conditions typical of Antalya, Turkey. An indirect forced convection solar dryer consists of a solar air heater and a drying cabinet. The solar air heater used for the modeled experiments was an insulated wooden frame about 0.9m in width and 1.8m in length, with a black-painted iron sheet used as absorber plate for absorbing incident solar radiation, and a transparent plastic sheet used as cover to avoid top heat losses. The drying cabinet was made of insulated wooden, with wire mesh trays on the bottom to hold the grapes, and an electrical radial fan in a chimney on top. Thus, ambient air was drawn into the dryer by the flow produced by the fan, and warmed in the heater before entering the cabinet.

The model studies the performance of a solar dryer with different air velocities, determined by the fan speed. The variation of air velocity determines the behavior of model variables through time: Temperature inside drying cabinet (*T*) and Moisture Ratio (*MR*). The temperature inside the drying cabinet is described by means of a state variable, as the moisture ratio. The moisture ratio (*MR*) estimated reflects the percent wet basis still present in the grapes. All equations on the model were derived from the study of several regression models, selecting those whose curves showed greater correlation with the empirical data extracted from the experiments conducted in Antalya (36º53'N,30º42'E). The experiments themselves were carried out during the periods of June to August 1997 and 1998. During the experiments in those drying seasons ambient air temperature ranged from 32.15 to 33.32ºC, air relative humidity from 66.43 to 75.7% and the solar radiation from 790.3 to 802.0W/m^2, being moisture content reported as percent wet basis and then converted to kg water per kg dry matter for modeling.

Air velocity (*V*=[m/s]) and temperature (*T*=[ºC]) are related by a concave function, which shows how the temperature inside cabinet vary as air velocity increases. This is described on the model as a 2nd order polynomial equation, see Eq.(1), obtained through regression analysis of the empirical data taken during experiments.

Moisture ratio is calculated with a two term equation model, obtained from the study of eight different regression models. The two-term model was selected as it showed the best correlation coefficient and the reduced χ-squares determined that it was a good fit to the curves. For calculations, MR was simplified to M/M_0 (moisture mass/initial moisture mass) instead of $(M-M_e)/(M_0-M_e)$ because relative humidity of the drying air continuously fluctuated in the solar drying process. This model shows moisture ratio decreasing continuously, the same as the drying rate, while the drying process takes places. Once in the clarifier, flow will split into a clarifying flow and a sedimentation flow. As result of these clarification and sedimentation processes, two different flows will exit from the clarifier: a sludge flow, which will be treated and disposed appropriately, and a clarified wastewater flow.

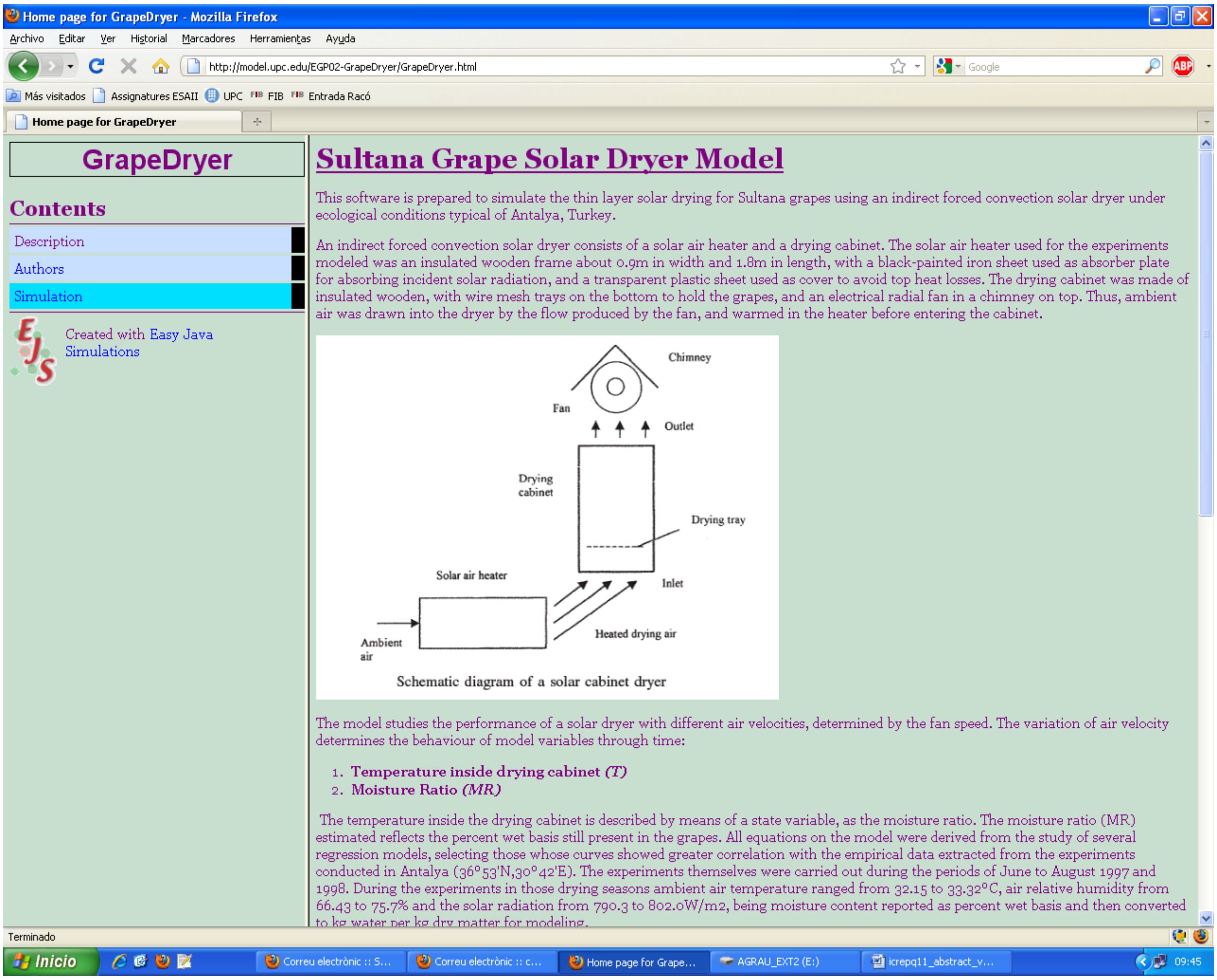

Figure 2. Solar system: Sultana Grape Solar Dryer

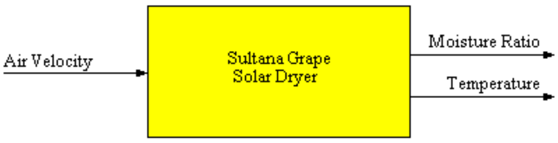

Figure 3. Block diagram of the Sultana Grape Solar Dryer.

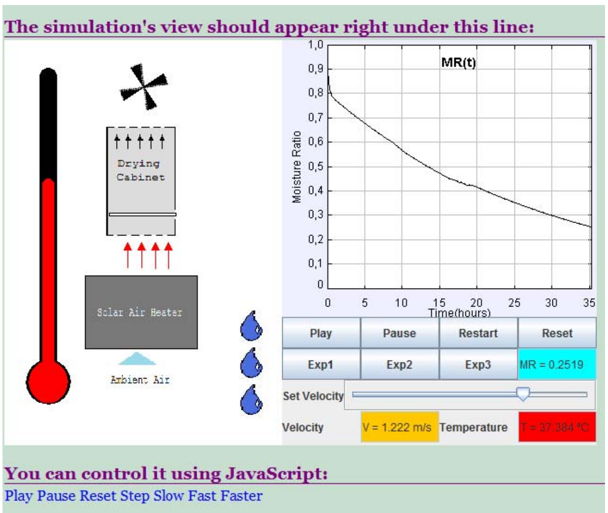

Figure 4. Web page: simulation results.

The results of the simulation are shown in the Fig. 4, model parameters can be changed during simulation using sliders.

Easy Java Simulations (*Ejs*) is a freeware, open-source tool developed in Java, specifically designed to create interactive dynamic simulations [11]. *Ejs* was originally designed to be used by students for interactive learning under the supervision of educators with a low programming level. However, the user needs to know in detail the analytical model of the process and the design of the graphical view. *Ejs* guides the user in the process of creating interactive simulations, in a simple and practical way.

4. Virtual Laboratory

The proposed laboratory practices about renewable energy are developed in the *Simulation and Modeling of Dynamic Systems* subject at the Industrial Engineering degree at UPC, consisting on the use of a virtual laboratory based on the Easy Java Simulations tool. The objective of this laboratory is to implement and test models related with Sustainability and Renewable Energies.

Teaching staff have an initial task of preparing the contents of the practice, and it consists on the following steps: 1) To develop the model of the real system by physical or empirical equations. 2) To implement the model with the *Ejs* in order to verify the equations, and propose a specific view. 3) When the above steps are perfectly done and the view is attractive enough, it is necessary to create a web page with the output of *Ejs*. This webpage will contain descriptive information about the practice, the objective, the methodology, the deadline and other academic information as well as the simulation results. These results have a great interest for the student because he/she can check which the expected results for the proposed practice are.

Once the practice is on the web, students can begin to do the practice in a local way. This aspect is very important because *Ejs* can be easily installed in their own PC and it is not necessary to be connected to Internet to do the job. *Ejs* can be installed for the most common operating systems. Then, the steps students must follow are:

1. Read attentively the practice. Previously, *Ejs* has been explained in the classroom and some exercises have been done by the students.
2. Implement the model with *Ejs*, following the ODE (ordinary differential equations) system proposed for the practices' instructor. Implement a view for the simulation results. Students have, as example, the results that instructor has published in webpage. It is not necessary *Ejs* installation to see the simulation execution because this is just a Java applet.
3. When the student finishes the implementation and the results are similar to the solution, he/she has to send the file where *Ejs* stores all the model equations, views and description. This information is stored in a XML file, and its size is relatively small. This is another feature of *Ejs*, the information is not in binary format nor codified in any way.
4. The instructor can easily evaluate the task of the student just compiling the XML file and checking the simulation results.

Using this method, two of the current problems in distance teaching are solved: temporary availability and the training aspect. Students/operators can practice anywhere at any time, without the need to go to a training centre or keep to a timetable (the teaching/training system will be available 24 hours a day via their computers).

From the faculty point of view, this method allows the addition of new practices in the webpage as well as new simulations results that students have to achieve.

5. Conclusions

Specifically, the demand on the available and finite energy resources is growing. New, efficient, and renewable energy sources are required in order to maintain our standard of living. Professionals are needed and must be proficient in sustainability concepts and experts in green engineering theories to lead the world through this period of transition. Then, introduction of sustainability and renewable energies is a challenge and a duty for the most advanced universities. In subjects of modeling and control of systems renewable energy laboratory practices are proposed. By those practices faculty want to achieve the stimulation of comprehension of the engineering field, to recognize the greening role of engineers ant to emphasize the more environmental aspect of engineering, specifically in aspects related greening energies. The assessment of these skills is not easy because they should be transmitted as experiences and attitudes.

Acknowledgement

This work has been funded by MCYT project DPI2007-61452.

References

[1] B. Aktan, C.A. Bohus, L.A. Crowl, and M.H. Shor, "Distance learning applied to control engineering laboratories," *IEEE Trans. Educ.*, vol. 39, no. 3, pp. 320-326, 1996.

[2] S.E. Poindexter and B.S. Heck, "Using the Web in your courses: What can you do? What should you do?" *IEEE Contr. Syst. Mag.*, vol. 19, pp. 83-92, Feb. 1999.

[3] K. Maly, H. Abdel-Wahab, C.M. Overstreet, J.C. Wild, A.K. Gupta, A. Youssef, E. Stoica, and E.S. Al-Shaer, "Interactive distance learning over intranets," *IEEE Internet Comput.*, vol. 1, no. 1, pp. 60-71, 1997.

[4] J.B. Patton and P. Jayanetti, "The making of multimedia power systems control and simulation labware," *IEEE Trans. Educ.*, vol. 39, no. 3, pp. 314-319, 1996. Available: http://www.ece.gatech.edu/users/192/web-use

[5] C. Schmid, "A remote laboratory using virtual reality on the Web," *Simulation,* vol. 73, no. 1, pp. 13-21, 1999.

[6] J. Sánchez, F. Morilla, S. Dormido, J. Aranda, and P. Ruipérez, "Conceptual learning of control by Java-based simulations," in *Proc. IEEE/IFAC Symp. Advances in Control Education* (ACE'2000), Gold Coast, Australia, 2000.

[7] O. Yaldiz, C. Ertekin, H.I. Uzun, "Mathematical modeling of thin layer solar drying of sultana grapes", *Energy*, vol. 26, pp 457-465, 2001.

[8] W. Shen, *et al.*, "Mathematical model of a solar module for energy yield simulation in photovoltaic systems", *Int. Conf. on Power Electronics and Driver Systems*, Taipei, Taiwan, November 2009.

[9] E.I. Ortiz-Rivera, *et al.*, "Bringing Renewable Energy to Electrical Engineering Undergraduate Education and Research at UPRM", *ASEE//IEEE Frontiers in Education Conf, San Antonio*, Texas, October 2009.

[10] Quadaih, Y.S. and Hiyama, T., "Utilization of Energy Capacitor Systems in Power Distribution Networks with Renewable Energy Sources*", J. Electromagnetic Analysis & Applications*, vol.2, pp.244-251, 2010.

[11] F. Esquembre, "Easy Java Simulations: A software tool to create scientific simulations in Java", *Comp. Phys. Comm.* 156 (2), pp 199-204, 2004.