



## Solar Energy Systems Course for Energy Engineering Students in the Context of the European Higher Education Area

Herminio Martínez-García, Jordi Cosp-Vilella

Barcelona College of Industrial Engineering (EUETIB)

Department of Electronics Engineering

Technical University of Catalonia (UPC). BarcelonaTech  
Campus de la Escuela Industrial de Barcelona. C/ Comte d'Urgell, n° 187  
08036 - Barcelona. SPAIN

Phone Number: +34.93.413.72.90; Fax Number: +34.93.413.74.01

E-mail: [herminio.martinez@upc.edu](mailto:herminio.martinez@upc.edu) , [jordi.cosp@upc.edu](mailto:jordi.cosp@upc.edu)

**Abstract.** The Bologna Process is a voluntary intergovernmental European cooperation initiative that led to the creation of the named European Higher Education Area (EHEA). EHEA was formed to promote mobility, increase academic recognition and attract students and staff from around the world to Europe. In this framework, since 2009, the Barcelona College of Industrial Engineering (Escuela Universitaria de Ingeniería Técnica Industrial de Barcelona – EUETIB) of the Technical University of Catalonia – BarcelonaTech (UPC) is offering the 4-year Bachelor Degree in Energy Engineering since 2009 with a total number of ECTS credits of 240. Current article deals with the inclusion of the sizing and design of solar energy systems in the context of this degree. In particular, and although this topic was eventually abandoned in the initial degree curriculum, the paper deals with the development of a 3<sup>rd</sup>-year course, Energy Integration, that focuses on this topic.

### Key words

University Education, Bologna Process, European Higher Education Area (EHEA), Energy Engineering Degree, Solar Energy Systems Course.

### 1. Introduction

Initially, the Bologna Process was started in the year 1998 (Sorbonne Declaration) by four countries (France, Germany, Italy, and the UK). From 1999, when the Bologna Declaration was launched, more countries joined. The European Higher Education Area (EHEA) was launched along with the Bologna Process' decade anniversary, in March 2010, during the Budapest-Vienna Ministerial Conference. At the same time, it was decided to continue the Bologna Process, at least until the year 2020 [1], [2].

As the main objective of the Bologna Process since its inception in 1999, the EHEA was meant to ensure more comparable, compatible and coherent systems of higher

education in Europe. Between years 1999 and 2010, all the efforts of the Bologna Process members were targeted to creating the European Higher Education Area, that became reality with the Budapest-Vienna Declaration of March, 2010. During current decade, the consolidation of EHEA will be aimed.

### 2. Current Bachelor's Degree in the Barcelona College of Industrial Engineering (EUETIB)

The Barcelona College of Industrial Engineering (EUETIB), is a center, associated to the Technical University of Catalonia (UPC-BarcelonaTech), which, with over 110 years of history, has been (since 1904) forming industrial experts, industrial engineers and engineering graduates over decades, focusing on four classic specialties of the industrial sector: Industrial Chemical Engineering, Mechanical Engineering, Industrial Electrical Engineering, and Industrial Electronics Engineering.

In 2009, the final extinction of Industrial Engineering plan (Spanish Plan 2002) was carried out, and the Center starts Engineering studies in the industrial field in the following degrees, under the guidance of well-known Bologna Process and the framework of the European Higher Education Area (EHEA):

- Degree in Chemical Engineering.
- Degree in Mechanical Engineering.
- Degree in Electrical Engineering.
- Degree in Biomedical Engineering.
- Degree in Industrial Electronics and Automation Engineering.
- Degree in Energy Engineering.

The authors of this article have focused mainly on the latter teaching degree (Energy Engineering), object of this work. The teaching of the authors has focused on two areas of this degree: Firstly, core courses in the third year of the degree, and, secondly, elective courses of fourth year. These elective courses are usually combined with the obtaining of the Bachelor's thesis (BT).

In this context, the Barcelona College of Industrial Engineering (Escuela Universitaria de Ingeniería Técnica Industrial de Barcelona – EUETIB) of the Technical University of Catalonia – BarcelonaTech (UPC), Barcelona, Spain, is offering the 4-year Bachelor Degree in Energy Engineering since 2009 (was launched along with the Bologna Process in the European Higher Education Area -EHEA- framework) with a total number of ECTS credits [3] of 240 [4]. These credits are divided into the four academic courses with a structure of the degree that has four blocks clearly distinguished (Table I):

- During the first year, the degree focuses on common courses in basics education for Engineering context (total 60 ECTS credits): *Mathematics* (24 ECTS), *Physics* (12 ECTS), *Chemistry* (6 ECTS), *Computer Science* (6 ECTS), *Graphic Expression* (6 ECTS), and *Business* (6 ECTS).

- During the second year, the degree focuses on common courses but in the Industrial Engineering context (total 60 ECTS): *Materials Science and Technology* (6 ECTS), *Electrical Systems* (6 ECTS), *Electronics Systems* (6 ECTS), *Industrial Control and Automation* (6 ECTS), *Mechanical Systems* (6 ECTS), *Fluid Mechanics* (6 ECTS), *Engineering Design* (6 ECTS), *Environmental Technologies and Sustainability* (6 ECTS), *Thermodynamics and Heat Transfer* (6 ECTS), and *Production Organization* (6 ECTS).
- During the third year, the degree focuses on specialization courses in the Energy Engineering context (total 66 ECTS): *Energy Resources* (6 ECTS), *Electrical Energy Generation* (6 ECTS), *Energy Transmission and Distribution* (12 ECTS), *Thermal and Fluid Dynamic Power Generation* (12 ECTS), *Energy Storage* (6 ECTS), *Energy Integration* (6 ECTS), *Control of Energy Systems* (6 ECTS), *Energy Sector Planning* (6 ECTS), and *Energy Management* (6 ECTS).
- Finally, during the fourth year, the degree focuses on elective courses (30 ECTS) and the Bachelor's thesis (24 ECTS).

Table I. – Structure of the 4-year Bachelor's Degree in Energy Engineering offered at the Barcelona College of Industrial Engineering (EUETIB) of the Technical University of Catalonia – BarcelonaTech (UPC). The credits are divided into the four academic courses with a structure of the degree that has four blocks clearly distinguished (blue, salmon, green and yellow boxes)

Q1	Mathematics I	Physics I	Computer Science	Graphic Expression	Chemistry
Q2	Mathematics II	Physics I	Business	Engineering Design	Materials Science and Technology
Q3	Mathematics III	Environmental Technologies and Sustainability	Mechanical Systems	Electrical Systems	Fluid Mechanics
Q4	Statistics	Production Organization	Industrial Control and Automation	Electronics Systems	Thermodynamics and Heat Transfer
Q5	Energy Resources	Thermal and Fluid Dynamic Power Generation I	Energy Sector Planning	Electrical Energy Generation	Energy Transmission and Distribution I
Q6	Control of Energy Systems	Thermal and Fluid Dynamic Power Generation II	Energy Storage	Energy Integration	Energy Transmission and Distribution II
Q7	Energy Management	Elective Course	Elective Course	Elective Course	Elective Course
Q8	Elective Course	Bachelor's Thesis (BT)			

### 3. Guided Activity (GA) at Barcelona College of Industrial Engineering (EUETIB)

At the EUETIB, the contents that are current curricula have been chosen to divide them into biannual courses of 6 ECTS credits each, except for some very particular courses such as the English Technical Communication, also biannual, but with 9 ECTS credits. Thus, a course of 6 ECTS credits, especially those that are part of the degree

specialty (core or elective), has its structure divided into the following four blocks (Figure 1):

- 1.2 ECTS credits for lectures (corresponding to 2 h/week).
- 0.6 ECTS credits for classes of problems (corresponding to 1 h/week).
- 0.6 ECTS credits for laboratory sessions (also corresponding to 1 h/week, but grouped into fortnightly sessions of 2 h).

- 3.6 ECTS credits of non-presential (NP) activities and guided activities (GA) (corresponding to 6 h/week).

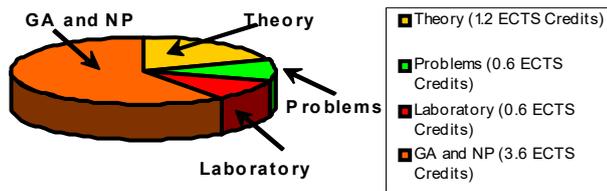


Fig. 1. Distribution of ECTS credits in current degree courses taught at the EUETIB.

In this figure, it is important to highlight that most workload involved in a particular course, and that the student must complete throughout the semester, is framed within 3.6 ECTS credits for non-presential off-site activities (NP) and guided activities (GA). In general, in these credits, course students must complete activities, tasks, works, etc., related, among others, to the following:

- Making activities, problems, etc., concerning topics explicitly explained or not by course professors in lectures, problem sessions and/or laboratory.
- Research, development and/or preparation by students of some topics that are not explained in class by course professors.
- Making reports of practice relating to laboratory sessions conducted in the course throughout the semester.
- Implementation of physical prototypes of energy plants, systems or equipment within the field of industrial engineering that is being considered in the course throughout the semester.

As it is well known, technical studies, especially those related to engineering, require a highly recommended (and, indeed, almost necessary) practical aspect. It serves not only as key from a practical point of view of this typology of University degrees, but also it can be used as a motivational tool to current students and future engineers.

This is a special key in engineering studies related to Energy Engineering. Indeed, the student of Energy Engineering, in addition of requiring theory course blocks that are used to analyze and design energy systems, plants and equipments (related to the lower levels of Bloom's taxonomy: Knowledge, comprehension, application and analysis), it also requires a special dedication to the simulation, assembly (implementation) and testing of these blocks, systems and equipments that have been designed or have been previously discussed in class lectures. These tasks correspond to the higher levels of the aforementioned Bloom's taxonomy: Synthesis and evaluation. While these levels of depth is not always done, due to time limitation or level of the course (staying at lower levels), in finalist courses of the degree it is important to reach these last Bloom's taxonomy levels, in order to carry out the idea of "globalization" for students.

This objective, unfortunately, is not always achieved. Moreover, if these finalists courses (usually elective courses) work together these "global" aspects within a common framework, the results can be quite encouraging. The idea of cooperative learning-based activity that is explained in this paper started as a result of the detection by course professors of a lack of students' motivation and academic level and capacity of the Bachelor degree in Energy Engineering.

Concerning undergraduate studies in Energy Engineering, within this load of guided activities, special emphasis is focused on the design, simulation, physical implementation (if it is possible) and test of a prototype energy plant, system or equipment. Indeed, all this process involves different stages which refer to all the actual process of developing energy plants, systems or equipment in an industrial or professional environment that students will encounter in a near future in their professional career:

- Design of the different single blocks of the energy plant, system or equipment to be carried out.
- Simulation of the aforementioned blocks individually, and simulation of the complete set when interconnection between them are carried out.
- If required or it is possible, physical implementation of the aforementioned individual blocks that form the system to carry out.
- If required or it is possible, testing of these individual blocks and experimental corroboration of their operation.
- If required or it is possible, assembly and installation of the blocks in order to obtain the complete plant, system or equipment.
- If required or it is possible, testing, experimental corroboration and obtaining of experimental results of the complete system or equipment carried out.
- Making of a technical report covering the entire process carried out, simulation results, experimental measures, economic budget, etc.
- Oral defense, with limited time, of the accomplished project carried out.

The development of this project is named in the course *cross project*.

#### 4. Solar Energy Systems Course

As we can observe, in the study planning of the degree there are not any specific courses on renewable energies and, in particular, on solar energy systems, and high-efficiency energy conversion. It is important to highlight that in the course *Energy Resources* (6 ECTS) [4], taught in the fall semester of 3<sup>rd</sup> year, the sun as an energy source is dealt (interest of the solar energy, potential, etc.). However, specifically, the sizing and design of solar energy systems is not dealt in this course.

As a consequence, the current teaching staff of the degree should find a solution to teach this essential part of Energy Engineering field. The solution was to consider the block as a part of the course *Energy Integration*, located in the spring semester of the 4<sup>th</sup> year [4]. This course consists of 45 lecture hours/semester (3 h/week) and 15 laboratory hours /semester (2 h/fortnight).

Therefore, as a consequence, the structure of the course consists of the following topics:

- DC-DC energy conversion and battery regulators.
- DC-AC energy conversion and solar inverters.
- Sizing of PV solar energy systems.
- Sizing of thermal solar energy systems.
- Sizing of water pumping based on PV solar energy.
- Integration of solar energy systems in the grid.

Therefore, having into account previous contents, the course cross project normally consists of in the design, simulation, and (if it is possible) physical assembly, implementation and testing of an energy plant, system or equipment. Some examples of cross projects are, for instance, the design and simulation of a complete PV solar plant to supply the energy requirements of a village, or the design, simulation and experimental implementation of a battery charger based on power DC/DC converters (buck, boost, etc.).

## 5. Evaluation and Remarks of the Experience Carried Out

Regardless of qualifications, to assess the activity carried out, information reported by the 'affected' people (i.e., course students) was used. It is important to highlight, after several detailed talks subsequent to the presentation and defense of the cross project, the good reception of the experience by students, although, in some groups, the results were not fully satisfactory (marks below 7 on a total of 10 points).

For most students, it was not the first time performed an evaluation experience of this kind. In fact, in different compulsory courses exposed in Table I (e.g., Energy Resources, or Energy Transmission and Distribution I), a part of the course includes the design, simulation, implementation and experimental corroboration of the operation for a more limited plant or system. In them, the goal is that the system has a good defined purpose, within the scope of the course itself, but its dimensions are generally dimensioned so that the same dedication from the student is limited. In this case, however, the cross project has a much larger and contained in different courses, although they are in the same area, try different topics within the field of Energy Engineering.

However, despite the difficulty and dedication that students exposed in making opinions collected, they expressed a number of strengths of the activity. From these points, there are three that should be emphasized:

- The development and progress of the cross project work are similar to a project that would take place in a company by a group of engineers. This brings involved courses (and their contents), and, especially, the degree, the imminent professional world for these students.
- Eliminates the "tightness" that currently have many of courses taught in the Spanish University. Our students often see the degree courses as a separate from the other courses, not only for different semesters different, but even for courses taught simultaneously in the same semester. For them, it is difficult to integrate and globalize different degree courses (compulsory or not) in a common framework. According to students, the cross project largely eliminates this sealing. As mentioned before, the idea of globalization, content integration and coordination is key point.
- It allows students to focus their degree Bachelor's thesis (BT) on a topic close to the cross project or close to that of the courses included in the intensification that serves as framework for the cross project. This idea is also key point to many students who are intensifying as a way to focus their careers in a certain area within the field of Energy Engineering.

Finally, as future research by part of coauthors of this study, we want to make a series of progressive improvements in the procedure carried out, which involves the following points:

- Mount the cross project as a learning system based on project-based learning (PBL) by technical puzzle. This will affect a greater time commitment within the course to carry out the project (sessions will be needed to make the expert meetings, to take time for explanation of an expert to the other members forming the group, etc.), but it will result in an improvement from the point of view of learning.
- Conduct a peer assessment set by the students enrolled in the course. Until now, assessment has been carry out by the course professors involved in the cross project. It is not excluded, however, that part of the final grade of the cross project is carried out by the course students themselves.
- Open the students' dissertations for previous semesters. This will allow to see what advanced students of the same degree have done. This would undoubtedly stimulate, encourage, and motivate these new students, who would see firsthand the "applicability" of their qualifications.

## 6. Conclusion

This article has shown the inclusion of the sizing and design of solar energy systems in the context of the

Bachelor Degree in Energy Engineering, offered at the Barcelona College of Industrial Engineering (EUETIB) of the Technical University of Catalonia – BarcelonaTech (UPC). In particular, and although this topic was eventually abandoned in the initial degree curriculum, the paper focuses on the development of a 3<sup>rd</sup>-year course, *Energy Integration*. The results obtained during four years of teaching of the aforementioned course, can confirm, on the one hand, the good acceptance of the course among Energy Engineering students, and, on the other hand, the good academic results obtained by them.

### **Acknowledgement**

This work has been partially supported by the Spanish Ministerio de Economía y Competitividad by project DPI2013-47799-C2-2-R

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