

# SIMULATORS FOR CONTROL ENGINEERS ADVANCED LEARNING

L. F. Acebes<sup>1</sup>, A. Merino<sup>1</sup>, L. Gómez<sup>1</sup>, R. Alves<sup>2</sup>, R. Mazaeda<sup>1</sup> and J. Acedo<sup>3</sup>

<sup>1</sup>*Department of Systems Engineering and Automatic Control, University of Valladolid  
Higher Tech. College of Industrial Engineering, c/Real de Burgos s/n 47011, Valladolid, Spain*

<sup>2</sup>*Department of Informatics and Automatic Control, University of Salamanca  
Faculty of Sciences, P/ de Fray Luis de León, 1-8, 37008, Salamanca, Spain*

<sup>3</sup>*Centro Superior de Formación de Repsol (CSFR), Madrid, Spain*

**Keywords:** Dynamic simulators, Continuous process control, Learning, OPC, Object oriented modelling languages.

**Abstract:** The paper purpose is to show a Windows© NT/XP/7 application oriented to learn control skills to process engineers and it is used successfully in an industrial master of instrumentation and process control. This tool contains two sets of process control problems that are very diverse ones, both in the type of process as well as control techniques (twenty three modules are available). It is possible to study cascade, ratio, selective, override and feedforward control techniques and the tuning, configuration and operation of PID controllers. It also allows analyzing complex systems control installed in boilers, furnaces, distillation columns or reactors and some special control techniques to ensure the process safety. When a module is selected a dynamic simulation and its graphical user interface are started. So, as example, one of the simplest modules is shown. Finally, an overview of the methodology and software used to develop this tool is also outlined. In particular, an object oriented modeling tool is used to develop the simulation models, a SCADA is used as graphical user interface and the simulation-SCADA communications are supported by the OPC standard.

## 1 INTRODUCTION

In nuclear, power, thermal, oil, gas, petrochemical, pulp and paper plants, as well as in other sectors, the use of process simulators is widespread, both for operators training and for production process improvement. Some examples of training simulators are APROS (VTT, 2011), Industrial System 800xA simulator (ABB, 2011), SimSCI-Esscor (Invensys, 2011), Team Aides (Tecnatom, 2011) or UniSim (Honeywell, 2011). These simulators are oriented to the operators training in particular industries and they are so much complex and high cost ones.

There are simulators oriented to the study of certain control subjects such as Loop-pro (Controlstation, 2011) or Topas (ACT, 2011). They are good tools to learn process control, but many advanced aspects of the industrial implementations are not considered. However, one advantage is that are not so expensive.

Other simulation packages, the so called design simulators, are oriented to build the process and control structure model and experiment with it. One

example in the field of engineering process is Hysys (Aspentech, 2011). Other examples of general purpose modelling and simulation tools are Dymola (Dynasim, 2011) or EcosimPro (EA, 2011). These modelling and simulation packages require that the user has a deep knowledge about them. Modelling and simulation skills are necessities, especially in some cases in which he should develop their own model libraries. Besides, for training purposes, the experimental frame is not the more suitable one and also its price is high.

These tools pursue different objectives ranging from PID controllers tuning, process identification, design of process and control structures, study of advanced control strategies, operation of process unit and, even, complete industrial processes. Some of them are reduced to a single industrial field and other ones cover a reduced number of processes. Some aspects of interest in the training of process control engineers cannot be covered by any of them. For instance: some special control aspects related to process safety, as anti surge mechanism in centrifugal compressors; special processes, as

blending processes; or parameterization procedures, as the linearization of the static operation curves of valves. In addition the graphical user interfaces (GUIs) are different ones, both in appearance and functionality.

So, to give a complete training to a control engineer requires the use of different tools that use dynamic simulation. This implies a high economic cost to the institution that provides training, both for the licenses purchase as for maintaining and updating them. For the students, it means an effort to adapt and learn different tools, some of which have many features that are not used by the students and they are being paid by the institution offering the training.

For these reasons, a simulation tool oriented to study typical problems of operation and control in production units of the process industry has been developed. The modules have been carried out by the *Department of Systems Engineering and Automatic Control of the University of Valladolid* and they are based on the expertise of control and instrumentation engineers of Repsol (a Spanish company in which one of its main activities is the production of petroleum derivatives). This tool is being used in the *"Master in instrumentation and*

*process control ISA-REPSOL"*) given by the CSFR (*"Superior Training Center Repsol"*).

The paper describes the mentioned tool. In particular, a simulation module will be shown as an example. Afterwards, the software structure of the simulation tool is detailed, as well as, the software used for its development

## 2 TOOL DESCRIPTION

The mentioned tool is a Windows® NT/XP/7 application that allows selecting a set of simulation modules organized in two graphical menus: "Control techniques" and "Process control units". The tool provides a help that explain each module in Spanish language. The great majority of the study cases are well explained in (Acedo J, 2003) and (Acedo J., 2006).

The "Process control units" modules are (Figure 1):

- Steam production boiler. Level and pressure control (ten coupled control loops).
- Boiler Burner Management System (BMS).
- Exothermic chemical reactor. Hydrodesulfurization process control.



Figure 1: "Process control units " menu.

- Endothermic chemical reactor. Catalytic reforming process control.
- Furnace. Temperature control (eight coupled control loops) driving two combustibles (fuel and gas).
- Distillation column. Two control structures and study of the economic and control aspects integration.
- Blending. Process control and mixture prescription specification.
- Automatic valves. Characterization of digital valve positioners.
- Heat exchangers. Cascade and feedforward compensators.
- Centrifugal compressors. Anti-surge mechanism.
- Alternative compressors. Two control options, load steps or split-range control.
- Centrifugal pump. Minimum recycling control of centrifugal pump.
- ON-OFF level controller. Dead band hysteresis effect and logic controller.

The “Control techniques” modules are:

- Ratio Control. Two options comparative for products mixture.
- Cascade control. Level tank control using cascade controllers. Mainly the tuning and the switching of the manual and automatic mode of the nested controllers are outlined.
- Selective control. Two cases, case 1 is a compression station control and case 2 is a pumping station control. Particular interest in the anti reset windup mechanism is shown.
- Feed forward control. Temperature control comparative in a heat exchanger without feedforward compensator and with a static or dynamic one.
- Split range control. This technique is applied to three systems. A pressure control in a distillation column head, a pressure control in a blanketing and a simultaneous flow and temperature control.

When a module is selected, from one of the main menus, the corresponding dynamic simulator and its GUI are started. Later, some details about the simulation are given. Now, the GUI of each module will be the focus of attention.

The GUI of the selected module corresponds to a P&ID (ISA, 1992), Piping and Instrumentation Diagram. These schematics have passive components that show information as standing or running equipment indicators, trend and historical

charts, other types of charts (characteristic valve curves), value displays,... and active components that allow acting over the system: starting or stopping pumps, valves or process units; selecting automatic/manual/cascade mode in controllers; modifying the boundary condition and the process and control parameters,...

By default the simulation runs in real time, but the user can change the simulation run speed using a time factor that can be greater than 1 to accelerate it, if the PC allows it, or lower than 1 to decelerate it (Figure 2).

### 3 EXAMPLE

In order to show how works the simulation tool, one of the simplest modules has been selected (minimum recycling control of centrifugal pump). First, a physical system description and the GUI will be outlined. Second, an experiment is run.

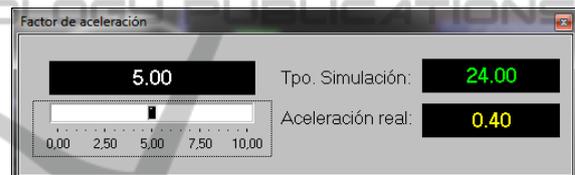


Figure 2: Time factor.

The system (Figure 3) is composed by a tank that receives a flow of water, a centrifugal pump connected to the tank outlet, a recirculation valve (V1) and an outlet valve (V2). The level controller (LC1) output is connected, in cascade, with the flow controller (FC2). The FC2 output drives V2. At the pump outlet, there are two pipes; one is connected to V2 and the other one to V1. The recirculated flow (FI4) is governed by the flow controller (FC1) that drives V1.

The aim of the control structure is ensure that, regardless of the LC1 actions, the pumped flow (FC1) must be always greater that a minimum value in order to avoid both thermal, mechanical or electrical problems and the pump cavitation. So, the Set Point (SP) of FC1 is the minimum pumped flow, which is a manufacturer specification. All controllers are implemented by PIDs (Proportional, Integral and Derivative). The process disturbance is the external flow to the tank (FI3). Besides, there are two alarm indicators to high and low level in the tank. The module allows modifying the PIDs parameters and observing the control structure performance when the feed flow changes, in

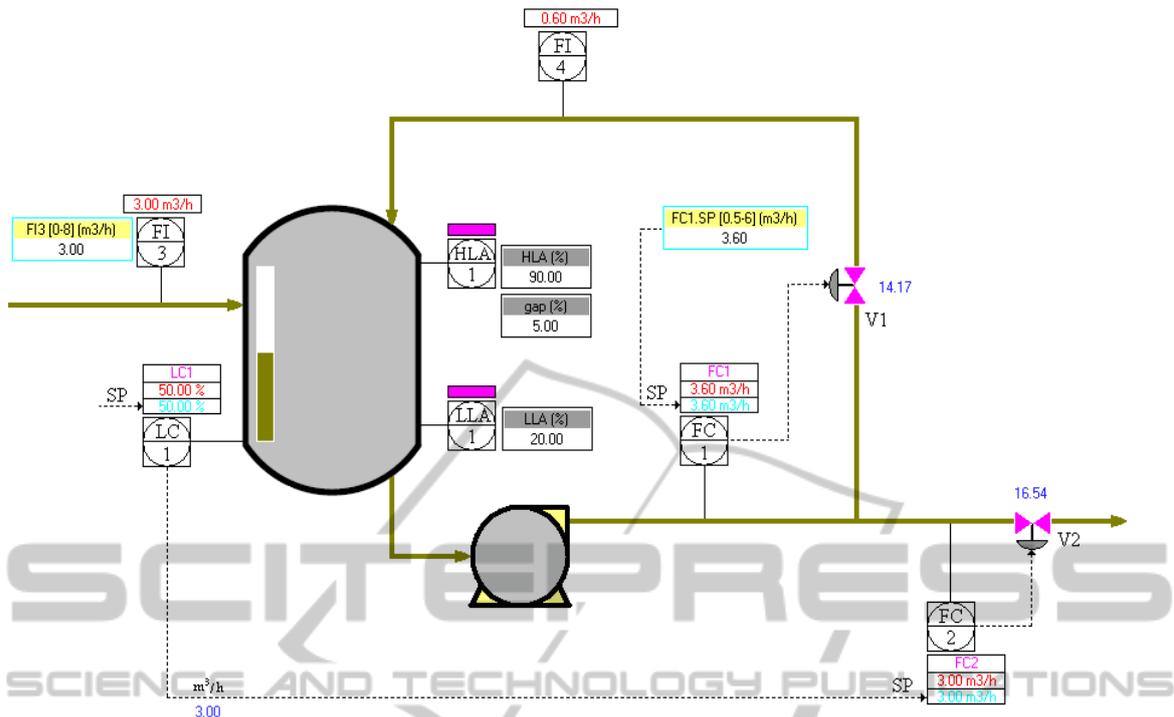


Figure 3: Minimum recycling control of centrifugal pump.

particular when it is less than the minimum pumped flow.

FI3 and FC1 SP can be modified using a step, ramp, oscillatory or random signal. The user must click on the corresponding indicator of the P&ID. So, an experiment is made in which a step from 5 to 3 m<sup>3</sup>/h in FI3 signal is activated (Figure 4).



Figure 4: Change boundary condition.

Initially, the outlet and pumped flow are equals and greater than the minimum pumped flow (3.6 m<sup>3</sup>/h) and therefore V1 is closed and FI4 is zero. As FI3 step result, FC2 and FC1 will be under the minimum pumped flow

and the controller of minimum flow must act. First, FI3 decreases from 5 to 3 m<sup>3</sup>/h. The tank level decreased and LC1 acts decreasing FC2 SP. Consequently, the outlet and pumped flows (in figure 5 FI1 and FI2) decrease simultaneously. When the pumped flow (FI1) is under the minimum pumped flow, FC1 acts opening V1 and, as result, FI4, the tank level and FI1 are increased and the pumped flow rises the minimum pumped flow value.

Clicking on the control signals or variables displays, trend charts showing the performance of the control structure are shown. These charts can be configured by the user. Figure 5 shows the flows performance.

PID controllers implement the main aspects of the industrial controllers. Pressing the left mouse button placed on each PID controllers, the GUI for managing the corresponding PID is shown (Figure 6). The bar graph lets you see (graphically and numerically) the value of the process variable (PV in blue), set point (SP in red) and control (OP in yellow). The user can select the controller mode (Automatic, Manual or Cascade). In AUTO mode, he can specify the SP value and, in MAN mode, he can activate the SP tracking mechanism to avoid the well-known “bumpless” of the auto/man controller commutations.

Pressing the “AJUSTE” button the user accesses.

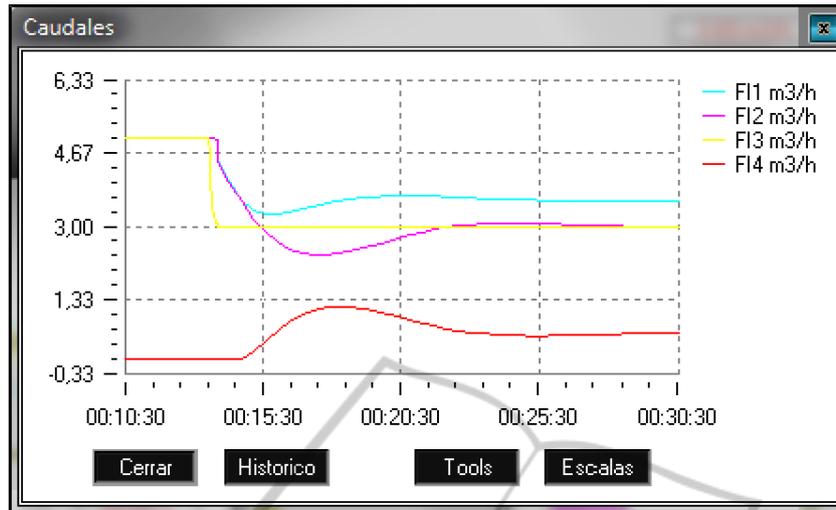


Figure 5: Process and control structure response.

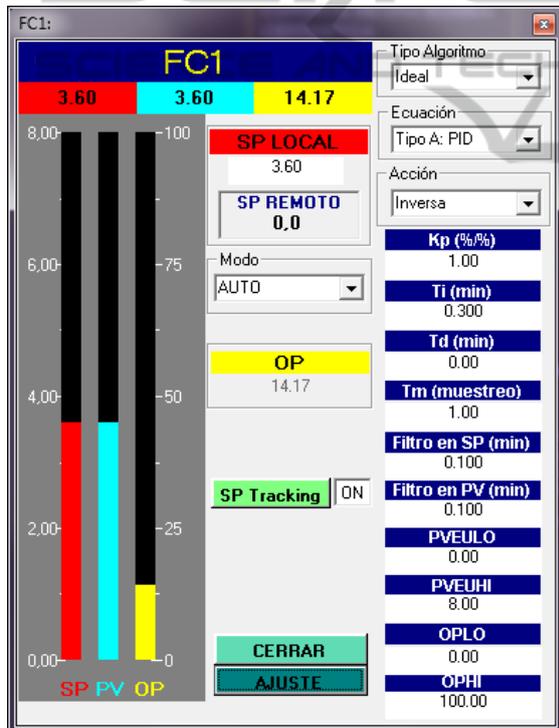


Figure 6: PID interface.

to the tuning parameters (proportional gain, reset time, derivative time, sampling period, SP and PV time constant filters, PV and OP span values in Engineering Units). Additionally, there are three menus to select the type of algorithm (Ideal or Interactive), the PID equation (PID, PI-D, I-PD, I) and the action controller (direct or reverse). The PID equations use normalized SP, PV and OP values.

#### 4 SOFTWARE STRUCTURE AND DEVELOPMENT TOOLS

When selecting a particular module a SCADA system is started. This SCADA is called EDUSCA (Alves R. et al, 2006) and it is the simulation module GUI. EDUSCA starts the simulation program linked to the selected module. The development of each module GUI involves the EDUSCA setting, which is done by a drag & drop strategy through a setting tool (Figure 7).

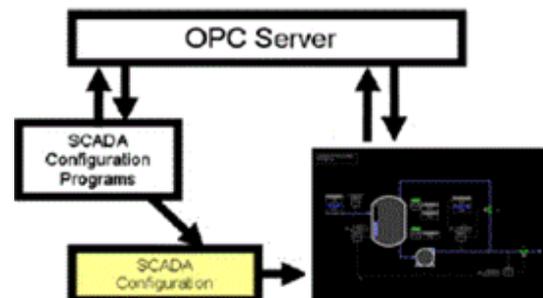


Figure 7: GUI setting.

The communication between EDUSCA and the simulation program is performed by the OPC (OLE for Process Control) communications standard for process control applications for Windows environments (OPC Foundation, 2011). EDUSCA acts as an OPC client and the simulation program as an OPC server.

The simulation models have been performed using EcosimPro. EcosimPro belongs to the so

called object oriented modelling languages (OOML). Many of the EcosimPro characteristics are similar to the modeling tools that implement Modelica (Modelica Foundation, 2011). In the sense that it supports non-causal models able to be modified automatically according to the context in which they are used. Its simulation language, called EL (Ecosimpro Language), allows the description of process models, named components, in a natural way by means of continuous differential algebraic equations and discrete events variables. Each component can have a ports based interface to connect to other components.

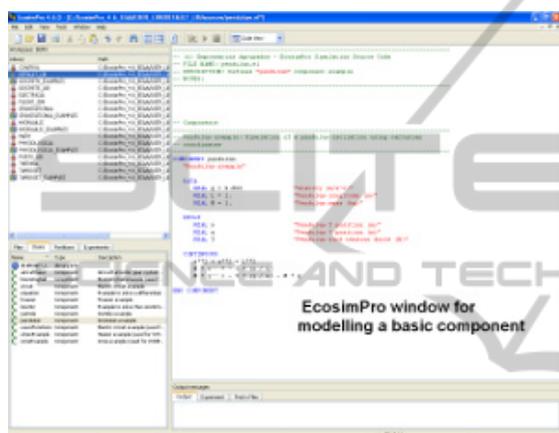


Figure 8: Ecosimpro textual modelling view.

These components are grouped in libraries and an icon can be attached to each one. The user can build the system model interconnecting components by ports, using directly the modeling language) or the GUI that allows the graphical modeling (Figure 9). Then, the resulting *mathematical model* is compiled and, after establishing a partition, that is, describing which variables constitute the known boundary conditions, EcosimPro generates the *simulation model* that is converted to C++ *simulation code* linked to the numerical solvers.

Finally, the user runs simulation experiments from another EcosimPro GUI view (Figure 10). In this project, two basic model libraries have been developed, one for process units and another one to design control structures. The mathematical models of the process units library components are based on first principles and the detail of the model is required for the purpose of the simulator. So, distributed or globalized parameter models can be found; fast dynamics can be explicitly modeled or simplified using static equations; empiric equations can be used to reduce the model complexity.

The EcosimPro simulation models don't hold

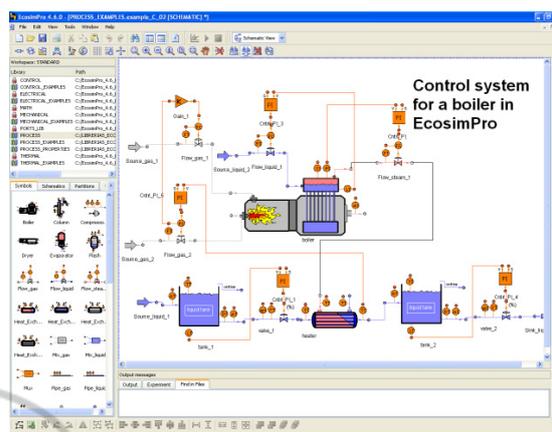


Figure 9: Ecosimpro graphical modelling view.



Figure 10: Ecosimpro experimental view.

OPC communications. However an OPC server can be created by adding to the C++ simulation code the communication routines provided by the OPC standard. Then, the simulation program is an OPC server can be accessed from any OPC client. This process can be automated. In our case, an application, CreaOPC (Alves R. et al., 2005), creates OPC servers from the sources files generated by EcosimPro.

## 5 CONCLUSIONS

A program with a library of simulation modules of typical control problems has been briefly exposed. This library deals with normal control problems (PID tuning; cascade, feedforward and ratio control)but, additionally, it includes other type of control problems (selective, override, split-range control) and special control strategies to guarantee security and quality process requirements. A variety

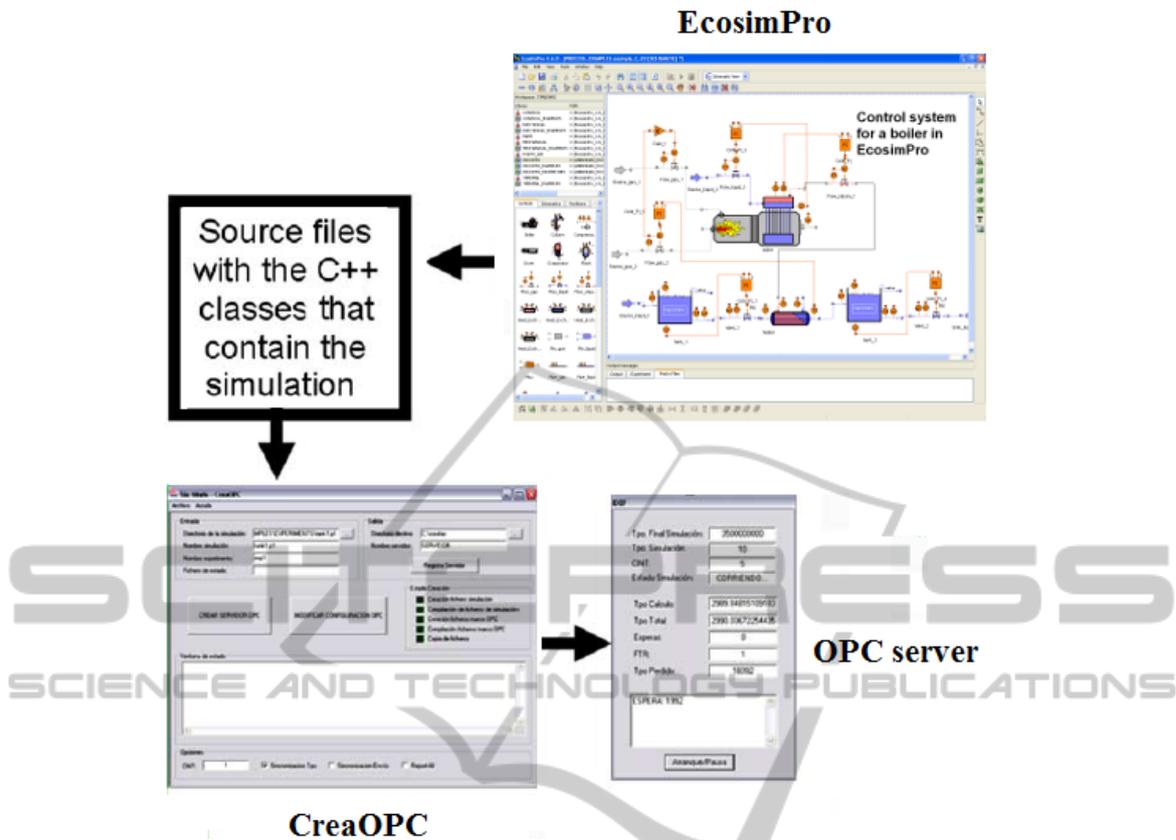


Figure 11: OPC server simulation generation.

of processes are considered, from the simplest ones, as tanks or heat exchangers, to the more complex ones, as boilers or distillation columns.

We consider that the program is user-friendly, few hardware and software resources are required and the functionality, the level of detail and the GUI are adapted to the industrial environment and the learning requirements for control process engineers. Moreover, it has been validated by experts with industrial skills. So, it's used successfully in the "*Master in instrumentation and process control ISAREPSOL*".

Finally, to make the simulation based learning tool for control engineers a diverse set of programs and EcosimPro libraries have been developed:

- Two complete EcosimPro model libraries of unit process and control elements. They can be used to design and test different control structures to production process.
- EDUSCA: a SCADA and its setting tool. EDUSCA can be used for different purposes to the outlined one in this paper. It can access to any OPC server and, consequently, it can be used to supervise laboratory plants or any OPC

server simulator.

- CreaOPC, to generate OPC server simulation programs from the EcosimPro simulation models. So, the OPC server simulators can be connected to any OPC client, for instance any industrial SCADA.

Additionally, as future work, new modules can be added to the library, for instance a multivariable predictive control module. Other possible development and research line is to follow up EDUSCA to support the web based learning.

## ACKNOWLEDGEMENTS

The authors want to express their gratitude to the ISE (Instituto Superior de la Energía, Fundación Respsol-YPF) and to the ISA (International Society of Automation) Spanish Section for the financial and technical support.

## REFERENCES

- ABB, 2011. Industrial System 800xA simulator by ABB. [Online]. Retrieved from <http://www.abb.com>
- Acedo J., 2003. *Control avanzado de procesos. Teoría y Práctica*. Ediciones Díaz de Santos. ISBN: 84-7978-545-4
- Acedo J., 2006. *Instrumentación y control avanzado de procesos*. Teoría y Práctica. Ediciones Díaz de Santos. ISBN: 978-84-7978-754-7
- ACT, 2011. Topas by ACT. [Online]. Retrieved from <http://www.act-control.com>
- Alves R. et al., 2005. "OPC based distributed real time simulation of complex continuous processes". *Simulation Modelling Practice and Theory*. Volume 13, Issue 7, October 2005, Pages 525-549. ISSN: 1569-190X
- Alves R. et al., 2006. "EDUSCA (EDUCational SCAdA): Features and applications". *Advances in Control Education*, Volume 7, Part 1. *Proceedings of the 7th IFAC Symposium on Advances in Control Education*
- Aspentech, 2011. *Hysys by AspenTech*. [Online]. Retrieved from <http://www.aspentech.com>
- ControlStation, 2011. *LoopPro by ControlStation*. [Online]. Retrieved from <http://www.controlstation.com>
- Dynasim, 2011. *Dymola by Dynasim* [Online]. Retrieved from <http://www.dynasim.se>
- EA, 2011. *EcosimPro Dynamic modeling and simulation tool by EA Internacional*. [Online]. Retrieved from <http://www.ecosimpro.com>
- Honeywell, 2011. *UniSim by Honeywell*. [Online]. Retrieved from <http://hpsweb.honeywell.com>
- Invensys, 2011. *SimSCI-Esscor by Invensys*. [Online]. Retrieved from <http://iom.invensys.com>
- ISA-The Instrumentation, Systems, and Automation Society, 1992. *Instrumentation Symbols and Identification*. ISA-5.1-1984 (R1992). Formerly ANSI/ISA-5.1-1984 (R1992)
- Modelica Foundation, 2011. [Online]. Retrieved from <http://www.modelica.org>
- OPC Foundation, 2011. [Online]. Retrieved from <http://www.opcfoundation.org>
- Tecnatom, 2011. *TEAM\_AIDES by Tecnatom*. [Online]. Retrieved from <http://www.tecnatom.es>
- VTT, 2011. *APROS Process Simulation Software by VTT Technical Research Centre of Finland*. [Online]. Retrieved from <http://www.apros.fi>