Educational Simulators for Industrial Process Control

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Abstract. The paper shows a Windows© NT/XP/7 application oriented to learn control skills to process engineers. It is a dynamic simulation based tool with a friendly user interface that contains two sets of diverse process control problems (more than twenty study cases are available). It is possible to study typical control problems as cascade, ratio, selective, override and feedforward control techniques and the tuning, configuration and operation of PID controllers. Additionally, it allows analyzing complex control systems installed in boilers, furnaces, distillation columns or reactors and special industrial control techniques to ensure the process safety. In order to outline the functional features of the tool, one of the simplest modules is shown. To conclude, an overview of the methodology and software used to develop this tool is also outlined. In particular, an object oriented modeling and simulation tool is used to develop the simulation models, a self-developed SCADA is used as graphical user interface and the simulation-SCADA communications are supported by the OPC standard. Finally, it must be remarked that this tool is used successfully in an industrial master of instrumentation and process control.

Keywords: Dynamic Simulators, Continuous Process Control, Learning, OPC, Object oriented Modelling Languages.

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 [1-6]. 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 Looppro [7] or Topas [8]. 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 [9]. Other examples of general purpose

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modeling and simulation tools are Dymola [10] or EcosimPro [11]. These modeling and simulation packages require that the user has a deep knowledge about them. Modeling and simulation skills are necessaries, 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 derivates). This tool is being used in the "Master in instrumentation and process control ISA-REPSOL") given by the CSFR ("Superior Training Center of 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 main menus: "Control techniques" and "Process control units". The tool provides a complete help that explain each module in Spanish language. However, if more information is required, the great majority of the study cases are well explained in [12-13]. In order to give a general idea of the training capacity of the developed modules, these are listed and briefly described.

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.

Fig. 1. "Process control units" menu

The “Process control units” modules are (Fig. 1):

- Steam production boiler. Level and pressure control (ten coupled control loops).
- Boiler Burner Management System (BMS). A security system to monitor the boiler and execute, in a safe way, all scripts to turn on and off the burners
- Exothermic chemical reactor. Hydrodesulphurization process control.
- Endothermic chemical reactor. Catalytic re-forming 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. The Blending is a batch process whose aim is to mix different components in appropriate proportions to meet a required specification. The simulated blending manages five components according to a mixture prescription that is defined by the user.

- Automatic valves. To study the importance of the control valves, the simulated system allows selecting the inherent characteristics of the valves and characterizing its digital smart positioners.
- Heat exchangers. The module aims to study the beneficial effect of using feedforward compensators and cascade control in simple systems such as heat exchangers.
- Centrifugal compressors. This module shows a control structure that prevents centrifugal compressors can enter in an unstable operation region:”anti-surge” mechanism.
- Alternative compressors. The simulated process is composed by an alternative compressor and a recycling system which aim is to compress all the gas that reaches the system. To avoid problems in the working of the compressor, the suction pressure is controlled using this recycled gas flow and the compressor load. Two control techniques can be compared: load steps or split-range control.
- Centrifugal pump. Minimum recycling control of centrifugal pump.
- ON-OFF level controller. The simulated system allows to study the well-known on-off control and pays attention in the hysteresis effect of the dead band and the logic of the controller.

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

Each GUI of the selected module corresponds to a P&ID [14], 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 scale factor that can be greater than 1 to accelerate it, if the PC allows it, or lower than 1 to decelerate it (Fig. 2). In this kind of process simulators is unusual to reduce the time scale factor because the system dynamic is slow or not so fast.

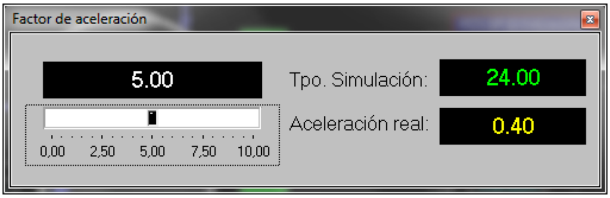

Fig. 2. Time factor

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.

The system (Fig. 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 water can be sent back to the tank and this flow (FI4) is governed by the flow controller (FC1) that drives V1.

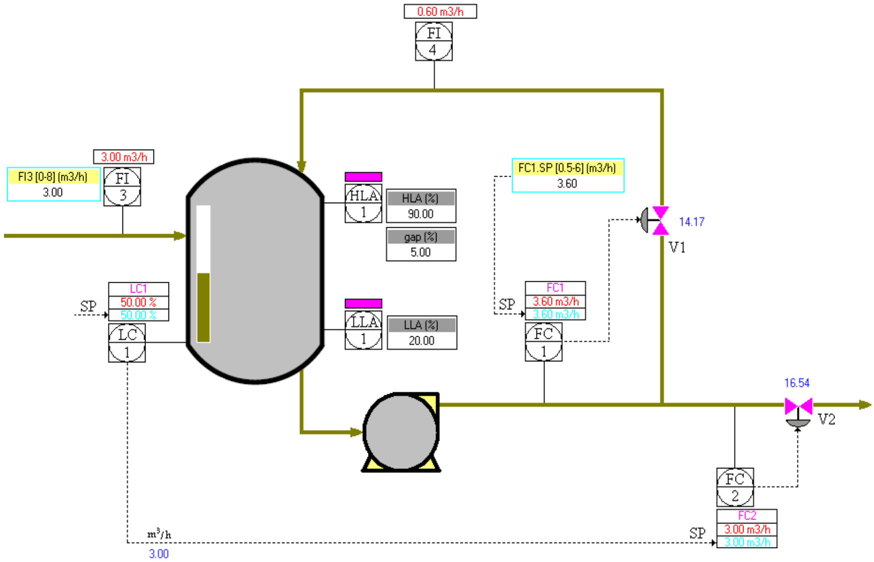

Fig. 3. Minimum recycling control of centrifugal pump

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 that can be changed by the user. All controllers are implemented by PIDs (Proportional, Integral and Derivative). The process disturbance is the external flow to the tank (FI3) and it is a boundary condition that can be modified by the user.

Besides, there are two alarm indicators at the P&ID scheme, one for high level (HLA1) and the other for low level (LLA1). The HLA1 indicator will be active and change its color when HLA1 is inactive and the level of the tank will be upper than 90% (HLA value), and HLA1 will be inactive and change it color again when HLA1 is active and the level will be minor than 85% (HLA-gap value). The values of HLA and gap can be modified by the user. The LLA1 indicator works in a similar way than the HLA1 indicator.

The module allows modifying the PIDs parameters and observing the control structure performance when the feed flow changes, in particular when it is less than the minimum pumped flow.

As it was previously mentioned, FI3 and FC1 SP can be modified using a step, ramp, oscillatory or random signal. The user must click on the corresponding

Fig. 4. Change boundary condition

indicator of the P&ID. So, an experiment is made in which a step from 5 to 3 m^3/h in FI3 signal is activated (Fig. 4).

Initially, the outlet and pumped flow are equals and greater than the minimum pumped flow (3.6 m3/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^3/h. The tank level decreased and LC1 acts decreasing FC2 SP. Consequently, the outlet and pumped flows (in Fig. 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 raises 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. Fig. 5 shows the flows performance and Fig. 6 the dynamic of the control signals.

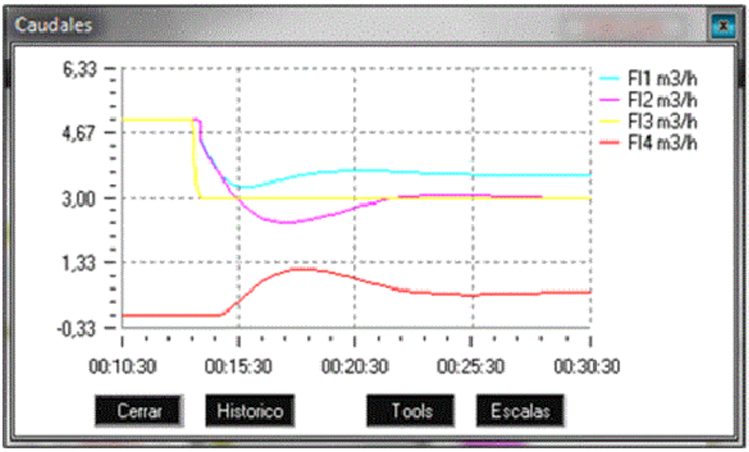

Fig. 5. Process and control structure response

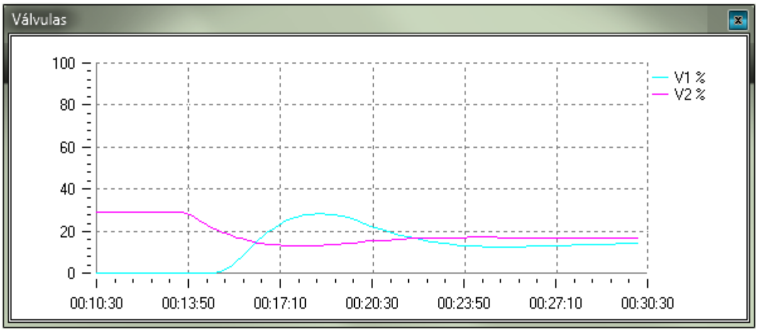

Fig. 6. Control Signals

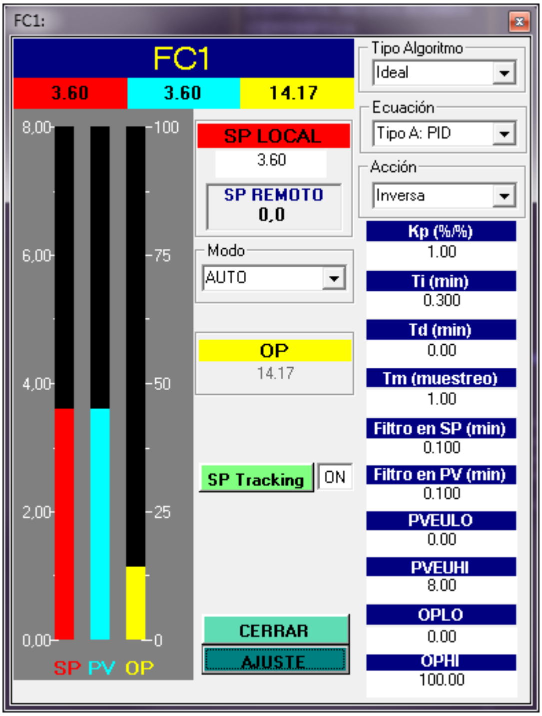

Fig. 7. PID interface

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 (Fig. 7). The bar graph lets you see (graphically and numerically) the value of the process variable (PV in blue), set point (SP in red) and output to process or control signal (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, the OP value. In manual mode, the user can activate the SP tracking mechanism to avoid the well-known "bumpless" of the auto/man controller commutations. With respect to the algorithm to calculate the control signal, it is possible to use diverse algorithm and PID structures and the PID calculus use normalized SP, PV and OP values.

Pressing the setting ("AJUSTE") button of the GUI of each PID, the user accesses to the tuning parameters: proportional gain (Kp), reset time (Ti), derivative time (Td), sampling period (Tm), SP and PV time constant filters, PV and OP span values in Engineering Units (PVEULO: Process Variable Engineering Units Low, PVEUHI: Process Variable Engineering Units High, OPLO: Output to Process Low, OPHI: Output to Process high). 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) that affects to the sign of the controller gain.

The previous experiment can be repeated with other FC1 controller parameters, for instance: Kp=5 and Ti=0.1. Then the control structure doesn't work well (Fig. 8).

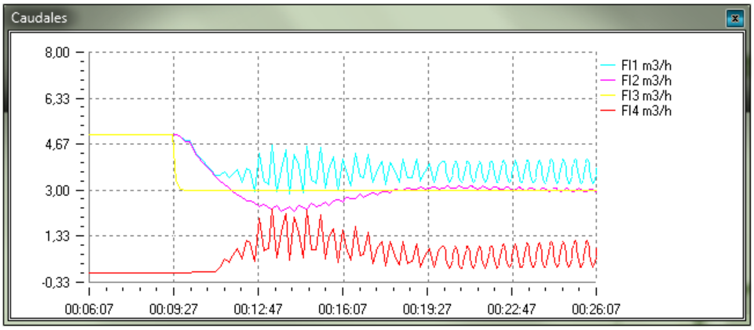

Fig. 8. Bad FC1 tuning: process and control structure response

4 Software Structure and Development Tools

When selecting a particular module a SCADA system is started. This SCADA is called EDUSCA [15] 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 (Fig. 9).

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 [16]. 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 modeling languages (OOML). Many of the EcosimPro characteristics are similar to the modeling tools that implement Modelica [17]. 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

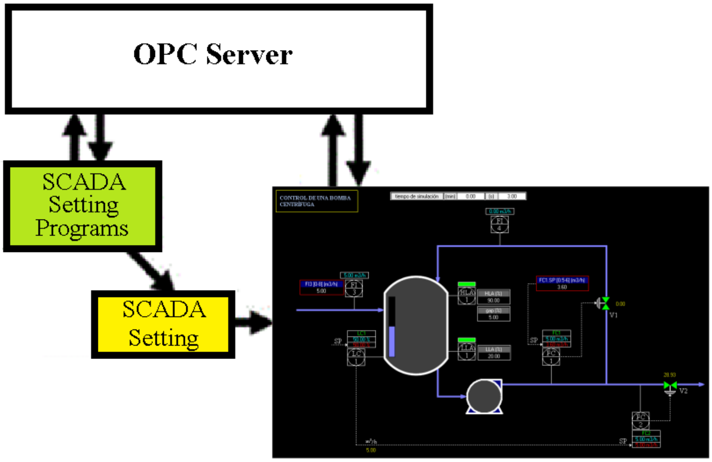

Fig. 9. GUI setting

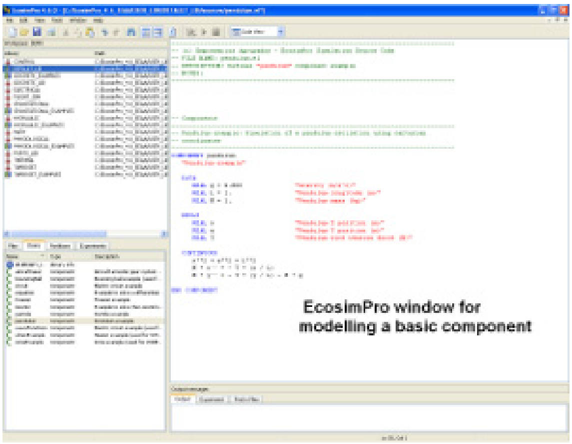

Fig. 10. Ecosimpro textual modelling view

(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. These components are grouped in libraries and an icon can be attached to each one. The user can built the system model interconnecting components by ports, using directly the modeling language (Fig. 10) or the GUI that allows the graphical modeling (Fig. 11).

Then, the resulting mathematical model is compiled and, after establishing a partition, that is describing which variables constitute the known boundary conditions and solve the problems related to the symbolic manipulation of the mathematical model (high index problems and tearing of algebraic loops), EcosimPro generates the simulation model. This simulation model is converted to C++ simulation code linked to the numerical solvers. Finally, the user runs simulation experiments from another EcosimPro GUI view: the experimental view (Fig. 12).

The experimental view of EcosimPro allows changing the values of the boundary conditions and parameters of the model and shows the numerical value of the model variables. So, it is possible to represent graphically the value of the model variables. The main problem is that the user must know the name of the variables in order to change or show their values and it is quite difficult if the user hasn't developed the model and if the model contains hundreds or thousands of variables. So, it is the reason why it looks like convenient to dispose of a friendly interface to use the simulation model by a user different to the model builder.

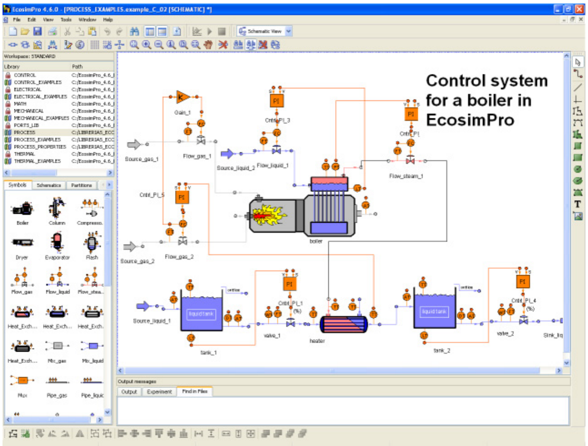

Fig. 11. Ecosimpro graphical modelling view

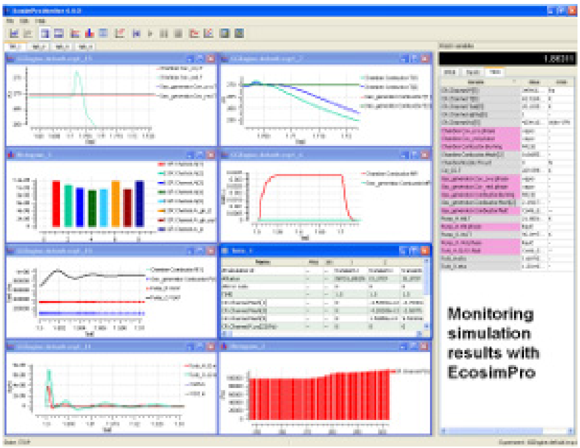

Fig. 12. Ecosimpro experimental view

In this project, two basic model libraries have been developed, one for process units and another one to design control structures. The library of mathematical models of process units is based on first principles and the degree of detail of the models is imposed for the purpose each 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, …

In order to use the EcosimPro simulation models from a GUI different from the experimental view, EcosimPro disposes of an add-in to execute models from Excel and another module to execute models from MATLAB. But, it isn't enough to communicate the EcosimPro simulation models with our GUI (EDUSCA), because the EcosimPro simulation models don't hold 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 converted to an OPC server can be accessed from any OPC client. This process can be automated. In our case, an application, CreaOPC [18] has been developed to set up OPC servers from the C++ sources files generated by EcosimPro (Fig. 13).

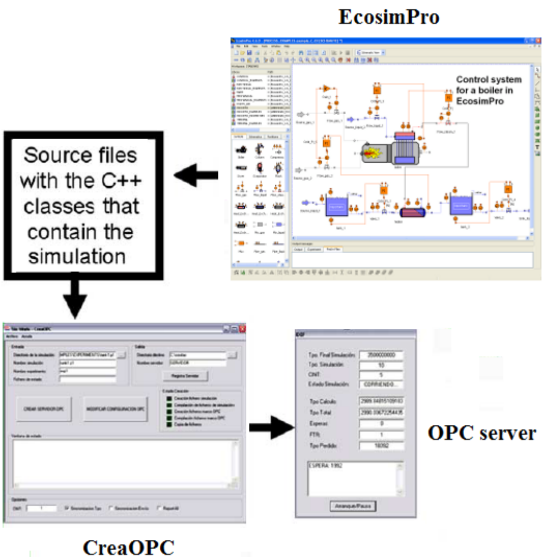

Fig. 13. OPC server simulation generation

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 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 ISA-REPSOL".

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 process unit 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 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.

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References

1. Industrial System 800xA simulator by ABB, `http://www.abb.com`
2. UniSim by Honeywell, `http://hpsweb.honeywell.com`
3. SimSCI-Esscor by Invensys, `http://iom.invensys.com`
4. TEAM_AIDES by Tecnatom, `http://www.tecnatom.es`
5. APROS Process Simulation Software by VTT Technical Research Centre of Finland, `http://www.apros.fi`
6. Acebes, L.F., Merino, A., Mazaeda, R., Alves, R., de Prada, C.: Advanced dynamic simulators to train control room operators of sugar factories. International Sugar Journal 113, 18–25 (2011)
7. LoopPro by ControlStation, `http://www.controlstation.com`
8. Topas by ACT, `http://www.act-control.com`
9. Hysys by Aspentech, `http://www.aspentech.com`
10. Dymola by Dynasim, `http://www.dynasim.se`
11. EcosimPro Dynamic modeling and simulation tool by EA International, `http://www.ecosimpro.com`
12. Acedo, J.: Control avanzado de procesos. Teoría y Práctica. Ediciones Díaz de Santos (2003)
13. Acedo, J.: Instrumentación y control avanzado de procesos. Teoría y Práctica. Ediciones Díaz de Santos (2006)

14. ISA-The Instrumentation, Systems, and Automation Society: Instrumentation Symbols and Identification. ISA-5.1-1984 (R1992). Formerly ANSI/ISA-5.1-1984 (R1992)
15. Alves, R., Normey-Rico, J.E., Merino, A., de Prada, C.: EDUSCA (EDUcational SCAda): Features and applications. In: Advances in Control Education, vol. 7, Part 1. Elsevier (2006)
16. Modelica Foundation, `http://www.modelica.org`
17. OPC Foundation, `http://www.opcfoundation.org`
18. Alves, R., Normey-Rico, J.E., Merino, A., Acebes, L.F., de Prada, C.: OPC based distributed real time simulation of complex continuous processes. Simulation Modelling Practice and Theory 13(7), 525–549 (2005)