

Graphical Environment for Modeling Control Systems in Full Scope Training Simulators

Guillermo Romero-Jiménez, Víctor Jiménez-Sánchez, and Edgardo J. Roldán-Villasana

Abstract—This paper describes the development of a control system model using a graphical software tool. This control system is part of an operator training simulator developed for the National Training Center for Operators of Ixtapantongo (CNCAOI, acronym according to its name in Spanish language) of the Mexico's Federal Commission of Electricity, CFE). The Department of Simulation of the Electrical Research Institute (IIE) developed this simulator using as reference the Unit I of the Combined Cycle Power Plant *El Sauz*, located at the centre of Mexico. The first step in the project was the developing of the Gas Turbine System and its control system simulator. The Turbo Gas simulator was finished and delivered to CNCAOI in March 2007 for commercial operation. This simulator is a high-fidelity real time dynamic simulator built and tested for accurate operation over the entire load range. The simulator was used primarily for operator training although it has been used for procedure development and evaluation of plant transients.

Keywords—Operators training, Power plant simulator, simulation environment.

I. INTRODUCTION

THE *El Sauz* combined cycle power plant is located at 130 km to the north of Mexico City, in the town of *El Sauz*, on federal highway 45. The power plant covers an area of 50 hectares. The power plant consists of 3 units with an effective capacity in site of 235MW with gas. The environmental conditions are: altitude of 1130 meters, 662 mmHg of barometric pressure; maximal summer temperature of 35°C, and up to -20°C minimal winter temperature.

The *El Sauz* power plant has three units of multistage FA, able to generate 690 MW (conditions ISO) and 505.8 MW conditions of site. Each unit consists of one Turbo Gas Westinghouse generator of 18 KV, the gas turbine is designed to burn natural gas and diesel, using a system of low nitrogen oxide emissions DLN2. The combustion gases are lead towards a Heat Recovery Steam Generator (HRSG), without additional combustion. The steam produced in the HRSG feed the steam turbo generator for generation of 54 MW to a potential of 13.8 KV, [1]. The power generated in both

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turbines, gas and steam, 18 and 13 KV respectively rises to 230 KV by means of a main transformer of wound double type in low tension. The side of high tension is interconnected to the Mexico's national electrical system. The generators are cooled by a mixture of water/Glycol in a closed circuit.

II. SIMULATOR DESCRIPTION

The CNCAOI, is devoted to train CFE operators of fossil-fuel power plants. To satisfy the CFE training requirements, the CNCAOI has: simulators based on control boards, classroom simulators, portable simulators and recently simulators based on MMI multi-window. A wide list of the main benefits in using a variety of training simulators is shown in [2], some of the most important are: the ability to train on malfunctions, transients and accidents; the reduction of risks to plant equipment and personnel; the ability to train personnel on actual plant events; a broader range of personnel can receive effective training; and individualized instruction or self-training can be performed effectively on simulation devices designed with these capabilities in mind.

This paper deals with the development of a Turbo Gas Simulator operated from screens of a Distributed Control System. The simulator models were developed using a standard FORTRAN Intel 9.1 language package, the MMI was developed using Flash (Macromedia) software and the control system model was constructed using a graphical environment software package called VISSIM[®]. This control system model is a replica of the SIEMENS[®] TelepermXP (TXP) Digital Control System. The methodology to develop the control system using a graphical and commercial software tool have several advantages: it allows an accessible and easy way to adjust, to correct and to up grade the control system model modifications. The following sections describe the simulator hardware, process models and the graphical control system model.

III. SIMULATOR ARCHITECTURE

The simulation software consists of a real time system dedicated to control and sequence the different simulator tasks, namely: instructor console, interfaces communication system, mathematical models and special tasks as environmental noises. All the software programs are written in C# language, the process mathematical models are written in Fortran language and the control system model was developed using the VISSIM graphical environment. One of

the aims of the project was to have a simulator with a modern hardware-software platform. The computing power and low cost of personal computers (PC), was the basis to select them as compute platform. Regarding the operating system, *Windows XP* was selected based on aspects of: portability, easiness of coding and available software for developing graphical interfaces.

The software packages used and required are: Windows Installer Framework 2.0, Microsoft Visual Studio .Net 2007, Flash 8 professional, DirectX 9.0, and Fortran Intel 9.1.

A. Hardware Architecture

The computer platform of the simulator consists of four Personal Computers interconnected through a fast Ethernet local area network. Each PC has a Pentium IV processor with 3.8 GHz, 1 GB of memory, and Windows XP as operating system. The Fig. 1 shows a schematic of this architecture.

The IC station is an instructor console with two 19" flat panel monitors, the OC1 and OC2 are operator consoles or stations, each one has two 19" monitors; the AC is an auxiliary operator console with two 50" monitors. The operator can use anyone of the OC1, OC2 and AC for monitoring and controlling any system of the simulated power plant. There is an additional PC, called maintenance station, which is used as a backup in the case IC is out of service, or it is used as a test station, this means that any software or process and control models modifications are tested and validated before any change can be done in the simulator. Therefore, this station must have all the software necessary to modify every simulator application.

However, the IC, OC1, OC2 and AC stations only use executable versions of the applications Microsoft Visual Studio .Net 2007.

B. Software Architecture

The software architecture of the simulation environment has three main parts: the real time executive, the operator module, and the instructor console module, [3]. Each of these modules is hosted in a different PC, and they are communicated through TCP/IP protocol. All the modules of the simulation environment are programmed with C#, with the exception of the Flash applications. A brief description of each module is shown in the next paragraphs.

C. Real Time Executive

The real time executive coordinates all simulation functions; it is constituted for six modules (Fig. 2):

1) Mathematical model launcher (DESMM)

Its function is to manage the execution sequence of each of the mathematical models. These models may be executed in a parallel scheme, with a distributed architecture of PCs or with a multi-core equipment. In this case is used the Task Parallel Library, which is designed for managing several applications in a multi-core equipment in a simple way.

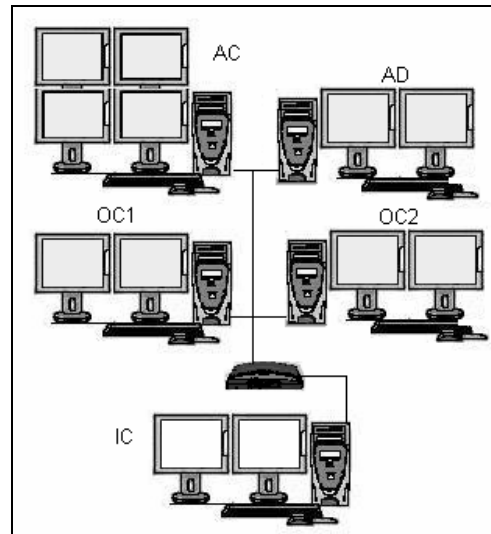


Fig. 1 Hardware Architecture

2) Manager module for interactive process diagrams (CORDPI)

This module executes the interactive process diagrams, provides the values of the variables, and receives/responds from/to the control commands messages of the operator module. Other functions of the module are to control the alarms system, to control the historical trends, to call the methods of each one of the equipment components (valve, pump, etc), to coordinate the timer for updating each one of the diagrams and to coordinate the sequence of events in the operation consoles.

3) Manager module for the global area of mathematical models (CORAGD)

It is composed for a group of methods for initializing the global area of state variables belonging to the mathematical models, these values are located in a table loaded in memory for a fast access. This module also synchronizes the access when a parallel process attempts to connect it.

4) Manager module for the instructor console (CORCI)

This module receives and responds the commands from/to the instructor console (stop, freeze, malfunctions, etc.) and executes the tasks in a synchronized way during a simulation cycle. Thanks to the TCP/IP communication, this module may be hosted in a different PC of the instructor console.

5) Main module (CORTR)

This module manages all the functions of the former modules.

6) Data base driver (MDB)

It is devoted to get, of each one of the data base tables, all the required information by the executive system.

D. Operator Module

The operator module is in charge of the operator MMI and manages the information flow with the executive system through the CORDPI module, so, a channel of bi-directional information is established through a TCP/IP socket. The MMI is constituted by interactive process diagrams which are *Flash* movies inserted in a "Windows way", using the "Fscommand"

interface for the communication.

The flash movies have static and dynamic parts. The static part is constituted by a draw of a particular flow diagram (replica of the real control diagrams); on the other hand, the dynamic part is configured with graphic components stored in a library, which are related to each one of the plant equipments, for instance, pumps, valves, motors, etc. These components have its own properties and they are established during the simulation execution.

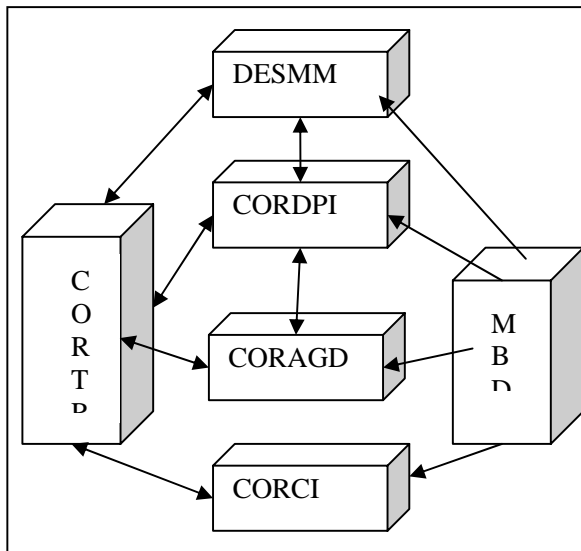


Fig. 2 Real time executive program architecture

The main parts of this module are: 1) a main module, which is an "Action-script" code which loads the interactive process diagrams, and gets information about the properties of the movie components; 2) a module for exchanging information with the main module and with the executive system; and 3) a module for the TCP/IP communications.

E. Instructor Console Module

This module is the instructor MMI and it is constituted by five modules: 1) a main module for executing all the tasks related with the graphical interface of the instructor; 2) a module for retrieving the static information of the simulation session, for instance, malfunctions, internal parameters, etc.; 3) a module for storing information in a data base using SQL; 4) a module for updating in a dynamic way the instructor console with the simulation information; and 5) a module for communicating the instructor console with the real-time executive.

F. The Man-Machine Interface

With the continuous progress in recent years of personal

computers technology, graphical user interfaces have become an indispensable tool in a day-to-day business, this interfaces, thanks to their multi-window environment, provides an easy-to-understand and easy-to-use MMI to power plants operators, [4].

The MMI for the training instructor is executed only in the IC. This MMI is a friendly windows application with pull-down menus and icons, as is shown in Fig. 3. The main functions of the IC are:

1) Run/Freeze

The instructor starts or freezes a dynamic simulation. The mathematical models of the control and process respond to the actions of the trainee in a very close way as it happens in the actual plant.

2) Initial Condition

It has the next options:

- To select an initial condition for beginning the simulation session. Each instructor has its own set of initial conditions (up to one hundred of them);
- To record a new initial condition (snapshot) or to erase an old initial condition;
- To specify the time interval for getting automatic snapshots.

3) Malfunctions option

It is used for introducing/removing a failure in any moment of the simulation session. There are 99 malfunctions. Examples of them are: pumps trips, heat exchanger tubes breaking, and control valve obstructed. All the malfunctions are grouped in systems and subsystems for an easy location. For the logical malfunctions, the instructor has the option of defining its time delay and its permanence time. For analog malfunctions, besides the former time parameters, the instructor can define their intensity and their evolution time.

4) Internal Parameters

The instructor has the option of insert internal parameters to simulate the operative actions not related with automatized equipment actions. These operative actions are associated with the local actions performed in the plant by an auxiliary operator. Examples of them are: to open/close valves and to turn on/off pumps or fans. In a similar way of the malfunctions, they are grouped in systems and subsystems and they can have time and intensity parameters as instructor options.

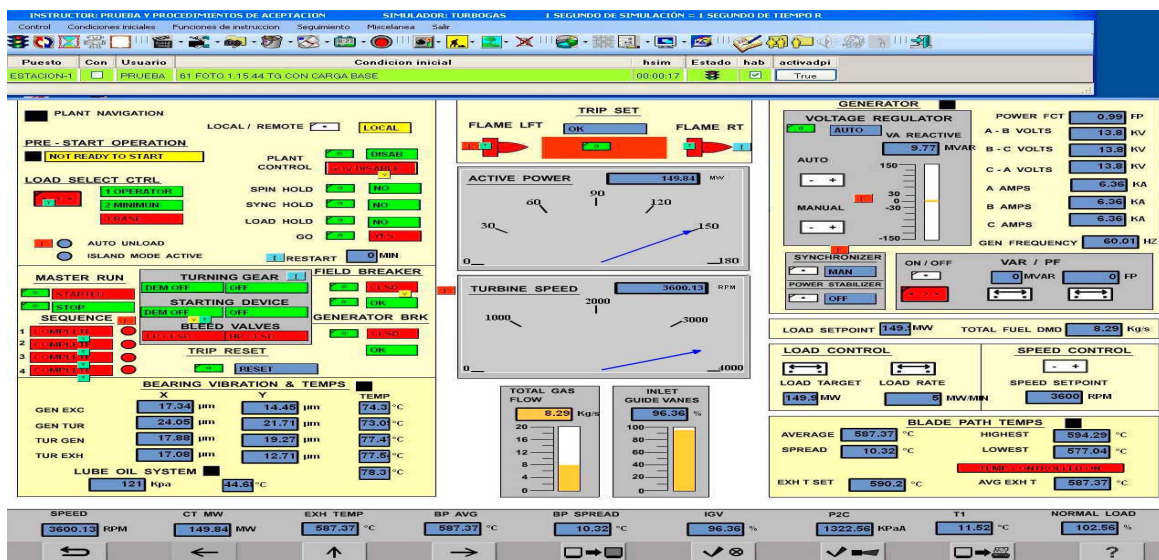


Fig. 3 Main Screen of the Instructor Console

5) External Parameters

This option allows the instructor to modify the external conditions to the process. These conditions are: atmospheric pressure, room temperature, voltage and frequency of the external electric system and fuel composition, between others.

6) Automatic Exercises

The instructor may create automatic training exercises. Each one of these exercises can include: initial conditions, malfunctions, local actions, and a time sequence. The exercises are stored for its subsequent use.

7) Faster than real time function

In its default mode, the simulator is executed in real time, but the instructor can execute the simulator up to ten times faster or up to ten times slower than real time. This option is especially important when the trainee wants to analyze a fast transient, therefore he can simulate in a slow way. In the other hand, some slow thermal process as turbine iron-heating can be simulated two, three or up ten times faster.

IV. PROCESS MODEL

The process models developed in FORTRAN language Intel 9.1, were constructed in a rigorous way and are based on fundamental, lumped-parameter conservation of mass, energy, and momentum. All process models were constructed to be accurate over the entire range from cold shutdown to full-load operation.

The executive program of the simulator, described above, coordinates the synchronization of models in a manner that is completely transparent to the instructor or operator trainee. All the process models operate as if they are a single executable program.

The plant process is divided into three groups: the first group simulates the compressor/turbine and combustor equipment, the auxiliary systems are simulated in a second

group; and a third group is used to simulate the electric system and generator.

Examples of models for each group are: Gas Fuel, Turbo/Compressor and combustor process models, [5]. 2.- Auxiliary systems as Lube, Seal, and control oil systems, Air instrument and Services, Glycol, Contaminant monitoring emissions, Gas Turbine Mechanics (Vibration and Supervisory System), and Electrical System, Excitation and Generator System, and Emergency diesel generator.

V. GRAPHICAL CONTROL SYSTEM

The control system model was developed using a graphical and commercial package VISSIM, and taking as reference the SAMA diagrams delivered by CNCAOI. VISSIM provides almost all the modules that were required. When it was necessary we have to develop modules, using the primitives of VISSIM we develop these modules and they were added to the VISSIM libraries. The SAMA diagrams, were re-drawn totally in VISSIM to reproduce all the control functions of the DCS. Also, 10 diagrams were designed to reproduce the automatic control not included in the DCS (and not available in the plant information) as the electrical system control, air to instruments and services control.

Special functions were developed to adjust the diagrams information into the simulator (functions to adjust the time delays for a discrete system like the simulator. Because the SAMA diagrams were obtained from the original files delivered by the plant constructor, some actualizations were not found and some printing errors were presented.

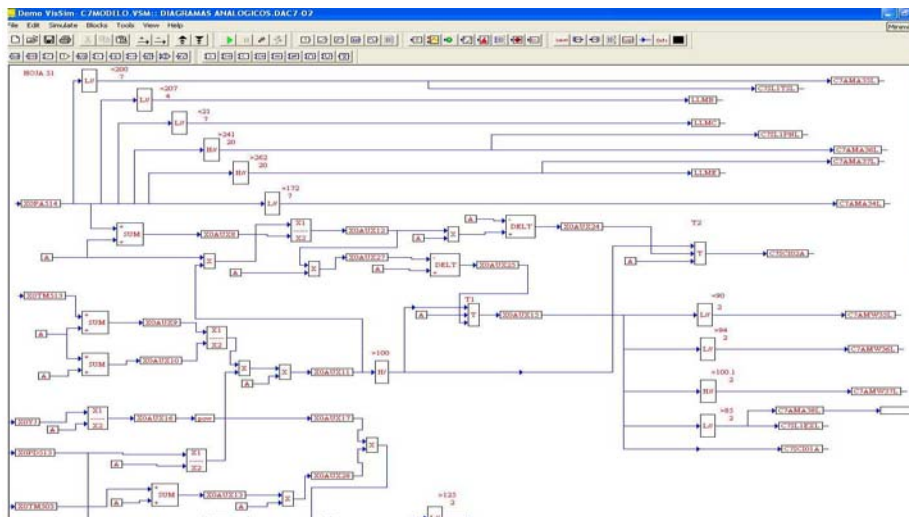


Fig. 4 A SAMA diagram into VISSIM package

The expertise of the CFE operators and IIE researchers were very important to get the adequate information from the plant behavior.

At the end, we took 200 SAMA diagrams in order to develop the complete control system, including protection logic, speed, temperature and load control over the entire range from cold to load 100%, [6].

In Fig. 4, we show an example of a SAMA diagram already presented in VISSIM format. Once all the control system model was re-drawn using the graphical environment, VISSIM generated a code in ANSI C language. This code was translated automatically into C# to be compiled and executed by the executive program of the simulator. The translation consisted in some adjustments in the generated C code, like nomenclature of local and global variables, the way to access simulator data base, etc.

During the development of the Turbo Gas Simulator, we keep always as source code, de Control System Model in VISSIM or graphical format. Thus, we have an easy way to access the control system model in order to make adjustments, corrections and validations.

VI. VALIDATION AND RESULTS

The simulator validation was carried out verifying its response against the 16 operation procedures elaborated by CNCAOI-CFE specialized personnel, denominated "Acceptance Simulator Test Procedures", [7].

This validation has as primary targets: to verify that the simulator accomplish satisfactorily the operation conditions from cold start to 100% of load; satisfy the steady states 25, 50, 75 and 100% of the nominal capacity; that the simulator has a correct behavior during the transients (with malfunctions included); and to guarantee the simulator robustness as a training system.

The adjustment of the simulator was carried out from cold

shutdown to 100% conditions. Figs. 5, 6, 7 and 8 show the tendency of some critical variables in the *El Sauz* Simulator, each figure show at the same time design and simulator generated data (considering that the available data from the plant were a hot start, so the temperatures do not begins at atmospheric conditions).

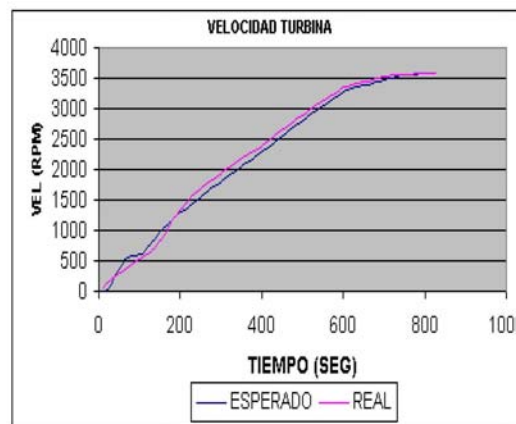


Fig. 5 Speed vs. time in a Turbo Gas Startup

VII. CONCLUSION

The el Sauz simulator is a high-fidelity, plant specific simulator for operator training. Realism is provided the use of extensive DCS screens emulation. The simulator is installed in the CNCAOI site located at Valle de Bravo, Estado de Mexico. This simulator is used for training of CFE Turbo Gas power plant operators. It was tested and validated by CFE personnel who have a lot of experience in the combined cycle power plant operation and in the use of simulators for qualification. After several adjustments on line, the behavior and dynamics of the simulator were very similar to those presented in the real plant.

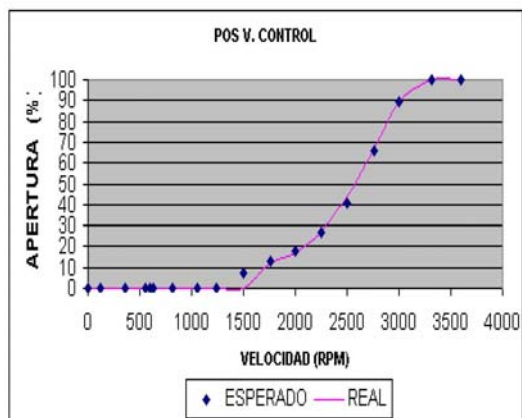


Fig. 6 Gas Control Valve vs. Speed

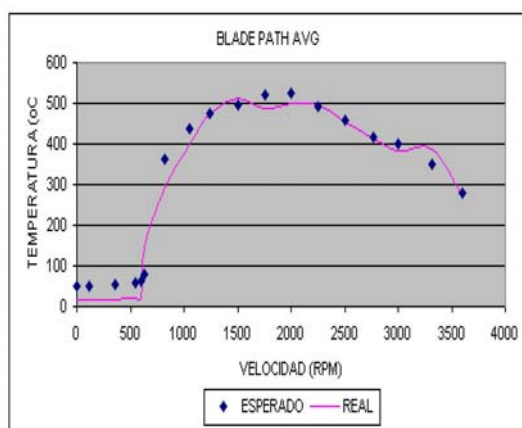


Fig. 7 Blade Path Temp. vs. Speed

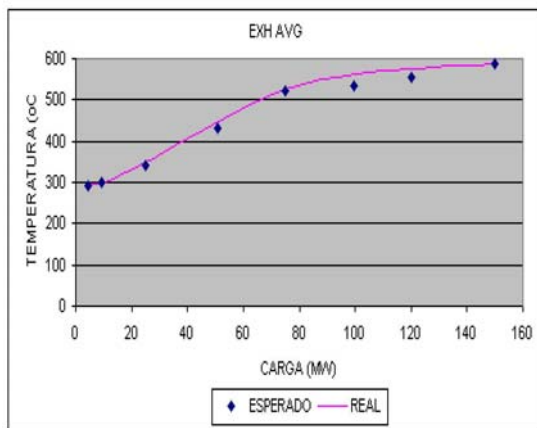


Fig. 8 Exhaust Temp. vs. Load over entire range

A very important aspect that gives a lot of certitude and robustness to the simulator behavior is that it has a high fidelity modeled DCS for gas turbine control of the real *El Sauz* power plant. Only minimum adjustments and changes in the controller parameters of regulation loops were required, which means that the process models that were obtained by the GS engineers reproduce with precision the real behavior of the reference plant.

Finally, it is necessary to mention all the benefits that are obtained with the best qualification that the operators obtain when using this simulator: the reliable operation of the power plants is guaranteed, the number of operation faults due to human errors is reduced, it can be possible to enable the operation personnel to train them into critical situations as emergency or failures cases, and the efficiency of power plants generation by improvements in its operation is increased.

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REFERENCES

- [1] CFE, "Prontuario de la Central de Ciclo Combinado El Sauz", Gerencia Regional de Producción Central, Subdirección de Generación, México, 2000.
- [2] International Atomic Energy Agency, "Selection, specification, design and use of various nuclear power plant training simulators", IAEA-TECDOC-995, 1998.
- [3] Jiménez-Fraustro Luis A., "Desarrollo del Medio Ambiente de Simulación para Simuladores Tiempo Real, basado en sistema operativo Windows XP", Reporte Interno, Gerencia de Simulación, IIE, 2005.
- [4] Yamamori, T., Ichikawa, T., Kawaguchi, S., Honma, H., "Recent Technologies in Nuclear Power Plant Supervisory and Control Systems", Hitachi Review, Vol. 49, No. 2, 2000, p61-65.
- [5] Edgardo J. Roldan-Villasana and Yadira Mendoza-Alegria, "Simulation Of a Power Gas Turbine System With A Generic Combustor Model", 2006 SCS, Summer Simulation Conf., Calgary, Canada, 2006.
- [6] Victor Jiménez-Sánchez y Guillermo Romero-Jiménez. "Desarrollo del Sistema de Control, Simulador Turbo-Gas", Proyecto. 13364, Gerencia de Simulación, IIE, 2007.
- [7] Romero G., "Revisión Conjunta de PPAs", Reporte Interno, Gerencia de Simulación, IIE, 2006.

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