Combined Cycle Power Plant Simulator for Operator's Training

E. Zabre, E.J. Roldán-Villasana, G. Romero-Jiménez, R. Cruz

Abstract—**This article presents the development of a Combined Cycle Power Plant Simulator for Operator's Training (SCCC). This simulator has been designed and developed by the Simulation Department of the Instituto de Investigaciones Eléctricas (IIE, Mexican Electric Research Institute). This is one more of the technological developments carried out by the Simulation Department, of Mexico's Electrical Research Institute and it is part of a full scale simulators group that belongs to the Comisión Federal de Electricidad (CFE, The Mexican Utility Company) which one the mayor electrical industries in the country. The simulator is actually under testing and evaluation by the final user, before putting on service at the National Center for Operator's Training and Qualification (CNCAOI). Tendencies of these development and impact within the operators' scope are also presented.**

Index Terms— **Control center, control room, simulator training, power plant.**

I. Introduction

In 1975 the Mexican Electric Research Institute (IIE*, http://www.iie.org.mx/site/about_us.htm) was founded. It has been the right hand as R&D institution of the Mexican electrical utility offering technical innovations. The Simulation Department (SD), one of the technical areas of the IIE has developed, installed, and integrated computer software systems and equipment in order to put on service and support a new computer platform of simulators for training personnel that operates control rooms of the electrical company. This time a full scale simulator of a combined cycle power plant is presented and its different parts are described within the training purposes. The developed simulator technology involves many areas and to reach the goals, different specialists were required. Engineers of software, processes modelling, control, communications network, maintenance and tests and faults have shared the same commitment.

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* Some acronyms are after the name or phrase spelling in Spanish.

II. Antecedent

According to Webopedia's Online Dictionary, a combined cycle in the generation of energy is defined as "The coexistence of two thermodynamic cycles in the same system", and simulation as "The process of imitating a real phenomenon with a set of mathematical formulas. In addition to imitating processes to see how they behave under different conditions, simulations are also used to test new theories". The definition above applies to the way the term simulation and the term simulator are used herein.

Generally speaking, a fluid of work: the gas and another fluid of work: the steam water, product of combustion, and a heat recovery steam generator, shape, generating energy in the so called combined cycle. A combined cycle power plant is very large, typically rated in the hundred of mega watts. If any combined cycle power plant operates only the gas turbine to generate electricity, and diverts the exhaust, there is a substantial loss of efficiency. A typical large gas turbine is in the low 30% efficiency range, but combined cycle plants can exceed 60% efficiency, because the waste heat of the gas turbine is used to make steam to generate additional electricity through a steam turbine, getting a high efficiency of electricity generation over a wide range of loads [7, 8]. The most modern combined cycle power plants implement innovative strategies in order to reduce emissions.

In 2006, the IIE's SD developed a Gas Turbine Full Scope Simulator (STG) [2] based on the Combined Cycle Power Plant "El Sauz", for the CNCAOI (located on Valle de Bravo, in the middle of the Mexican territory), using proprietary technology of the IIE, formed by a computer platform, Instructor Console Diagrams (DPI), and their respective mathematical models.

In this paper, the development of a SCCC based on 1, 2, and 3 unit's package from the Combined Cycle Power Plant Chihuahua II, as shown in Fig. 1 (also known as "El Encino", located on the north of the Mexican territory generates 450 MW and started operating on May 2001) is presented. The SCCC has a configuration of two gas turbines, one steam turbine, and two Heat Recovery Steam Generators (HRSG-1 and HRSG-2). One of the gas turbines derives from the actual CNCAOI's STG; the second one is a simplified gas turbine with a reduced scope, this means that it has the values of the main processes variables, so as to obtain the necessary thermal power for the steam turbine. Fig. 2 shows a typical diagram of the main components of a combined cycle power plant (with only one HRSG and without auxiliary systems,

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for simplicity).

Fig. 1 Combined Cycle Power Plant Chihuahua II

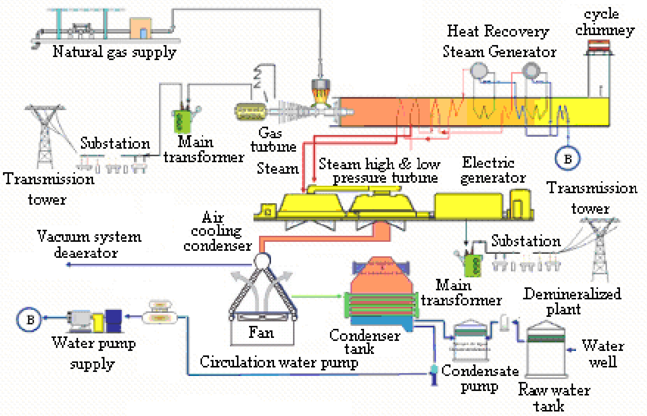

Fig. 2 Combined cycle power plant diagram

An advantage of this type of plant is the possibility of constructing them in two stages. The first one corresponds to the gas unit, which can be finished in a brief term and immediately initiate its operation; it is possible to later finish the construction of the steam unit, and the combined cycle to be completed this way.

III. ARCHITECTURE CONFIGURATION

A. *Conceptual main architecture*

In the SCCC several common systems are identified, as shown in Fig. 3. In the first instance, all modules are strongly related to a Real Time System to control and sequence the different tasks under the same operating system. The modules are as following:

1. Instructor Console. This is an important Man Machine Interface (MMI) of the instructor, which control and coordinates the scenarios seen by the operator under training. These scenarios could be presented to the operator as a steady state of the plant operation or under any failure of a particular system or equipment.
2. Interfaces communication system. This system allows to the operator to monitor and control plant parameters from three different sets of graphical interfaces: gas turbine, steam turbine and auxiliary emulated electrical external boards.
3. Mathematical models. This system has a set of mathematical models that represent all the necessary real representative systems of the plant.
4. Alarms and graphical variable tendencies. This system is capable to work as a reporter which presents the state of any pre-configured alarm of the malfunction system or out of range of particular variables.
5. And finally, the special task module which coordinates special tasks like environmental plant noises such as spinning turbine, start-up or shutdown pumps, etc.

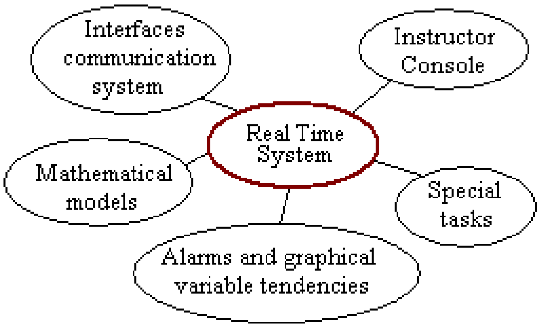

Fig. 3 Conceptual main architecture of the simulator

B. *Hardware architecture*

Unlike the power generation plants, combined cycle power plants (CCPP) represent a different alternative from commonly used plants in Mexico. As Fig. 4 shows, the SCCC is constituted by four Personal Computers interconnected through a fast Ethernet Local Area Network. Each PC has a mini-tower PentiumD$_{TM}$ processor with 3.6 GHz, 1GB of RAM memory, 40GB HD, and Windows XP$_{TM}$ as operating system. The Fig. 4 shows a schematic of this architecture.

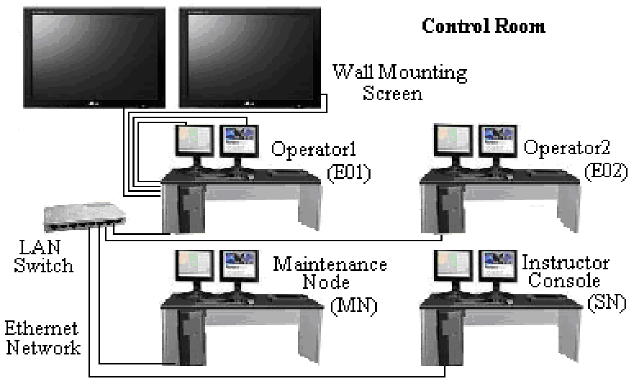

Fig. 4 Hardware architecture

The Instructor Console or simulation node (NS) PC has two 20” flat panel monitors, the Operator1 (E01) PC and Operator2 (E02), each one has also 20” flat panel monitors, but the E01turbo has two additional 42” flat panel monitors as auxiliary monitors.

There is an additional PC, the Maintenance Node (NM) which is used as backup in the case the Instructor Console is out of service. On this PC any modifications to the software or process or control models are tested and validated by an instructor before to install it in the simulator.

C. *Software architecture*

The SCCC has Windows XP_{TM} as an operating system, and was programmed in MS Visual Studio 2005: Fortran $Intel_{TM}$ for the mathematical models, Flash and $VisSim_{TM}$ for the gas turbine screens, the steam turbine screens were translated from the CCPP control, and C# for the modules of the simulation environment. The simulation environment, called MAS_R (proprietary software of the IIE [6]) has three main parts: the real time executive, the operator module, and the console module. Each module runs in a different PC, and all of them are communicated by means of a TCP/IP protocol. The modules of the MAS are programmed on C# under MS Visual $Studio_{TM}$ software development platform.

D. *Real time executive*

All simulation modules are coordinated by the Real Time Executive (RTE). The RTE is constituted basically for six main modules, as shown in Fig. 5.

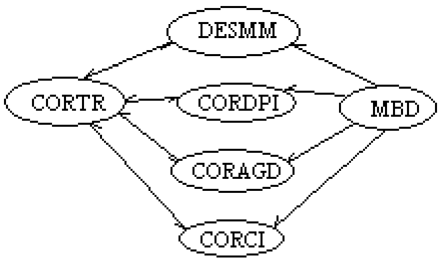

Fig. 5 Real Time Executive applications

1. Main module (CORTR). This module coordinates all functions of the following modules.
2. Mathematical model initiator (DESMM). Its main function is to manage the execution sequence of each one the mathematical models, which run sequentially in two processors within a 1/10 second execution frame.
3. Manager module for interactive process diagrams (CORDPI). This module executes all DPI and it works as input/output module, because it receives/responds to/from the control command messages of the operator module. The CORDPI also controls alarm systems and its historical trends.
4. Manager module for the global area of mathematical models (CORAGD). This module synchronizes the access when a parallel process requests to connect it.
5. Manager module for the Instructor Console (CORCI). This module coordinates all the functions under instructor request: run, stop, freeze, malfunctions, internal parameters, etc.
6. Data base driver (MBD). It is dedicated to receive/update any information required by the executive system. The SCCC uses about 27,000 variables.

E. *Instructor console*

The Instructor Console (CI) module is the Interface Man Machine, which is constituted by five modules interconnected among themselves as shown in Fig. 6. These modules work the following way:

1. Console Application. A module to communicate the CI with the real-time executive.
2. CONINS. A module to retrieve all the static information during simulation session, for example: malfunctions, internal parameters, local instrumentation, external parameters, etc.
3. BDSM. A module to store information in a data base using SQL programs interface. The data base can be updated by means of external tool as data base administrator system, known as $SABADAMAS_R$.
4. The mathematical models. The representation of the real plant systems.
5. DPI. The Instructor Console Diagrams or Graphical Interface of the instructor.

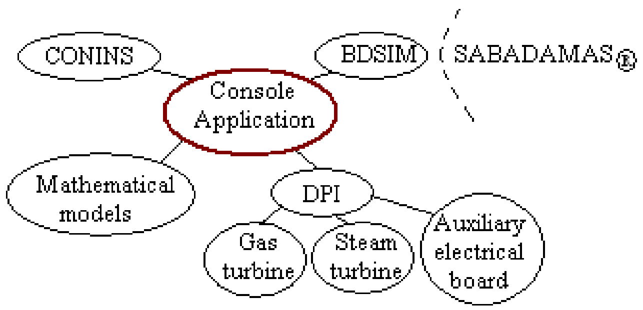

Fig. 6 Instructor Console Execution Diagram

The simulation session is controlled in the CI. The instructor has a main menu of functions as shown in Fig. 7. The main functions of the CI are the following:

Fig. 7 Main display of the Instructor Console

1. Run/Freeze. The instructor may start or freeze a dynamic simulating session. The mathematical models of the control and process respond to any action of the trainee in a very similar way as it occurs in the real plant.
2. Repetition, simulation session can be repeted as many times as the instructor sees fit.
3. Simulation speed. From the beginning of the simulation session the simulator is executed in real time, but the instructor may execute the simulator up to two or three times faster than real time. For example, slow thermal processes such as the turbine iron-heating can be simulated to occur faster.
4. Initial conditions. The instructor may select an initial condition to begin the simulation session, either from the general pre-selected list of initial conditions or from their own catalogue (each instructor has access up to 75 initial conditions). In this function, it is possible to create an initial condition or to erase an old one. The simulator is

capable of getting the automatic snapshooting function, every 15 seconds.

5. Malfunctions. It is used to introduce or remove a simulated failure of plant equipment, for example: pumps trips, heater exchanger tube breaking, electrical switch or valve obstruction, etc. The instructor–has the option to define the malfunction delay and its permanence time as well as the evolution time.
6. External parameter. The external conditions such as atmospheric pressure and temperature, voltage and frequency of the external system, among others can be modified by the instructor.
7. Actions register. This is an automatic registration of the actions carried out by the trainee in order to be re-played in the exactly the same sequence and time with the purpose of analyzing what the trainee did during the simulation session and to avoid possible mistakes in a real control session.
8. Development tools. The simulator has implemented some others helpful tools to use during simulation session development, for example: to monitor and change on line any selected list of global variable, tabulate any selected list of variable and tabulate them.

F. *Operator module*

The operator module consists of three main displaying sets of plant interfaces, from where it is possible to display any logical or analogical plant parameter and to operate and handle some manual or automatic controls related to the plant operation in order to maintain the optimal functional conditions, to monitor or graphic tendencies values of diverse parameters, and to re-establish to normal conditions, among others functions.

G. *Gas turbine interface*

The gas turbine interface (GTI), is a set of dynamic screens on which it is possible to monitor parameters concerning that include Control; ready to Start/Trips; vibration analysis; combustion flashback; lube oil system; trend overview; turbine cooling system; emissions; synchronization; TG2 simplified; etc.

H. *Combined cycle interface*

The combined cycle interface (CCI) is a traduction of the real plant control. There is an example shown in Fig. 8.

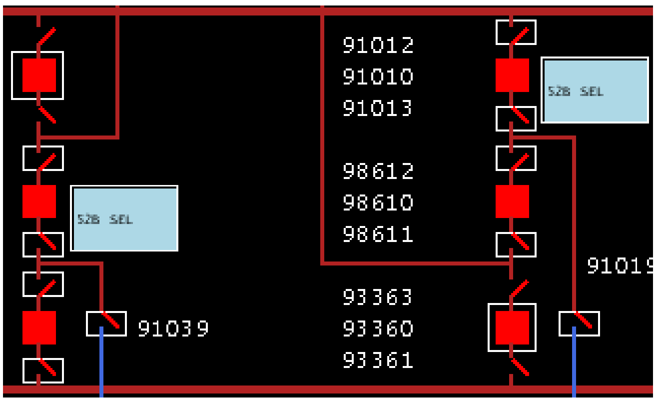

Fig. 8 CCI (detail) Circuit breaker of 230 KV SE bus

I. *Auxiliary electrical external board interface*

The auxiliary electrical external board (AEEBI) represents a couple of screens that lead all the necessary external instrumentation while synchronization loading takes place.

IV. Modeled Systems

On the SCCC–control models and process models were considered. The control models were translated by means of a graphical software tool, while the system processes were programmed on Fortran Intel$_{TM.}$

A. *Control system*

Generally speaking, the Distribuited Control System (DCS) is a set of PLC in where the algorithms to control are allocated, in an automatic or semi-automatic way, all the systems of a power plant. These control algorithms are organized in components with specific function or task, for example: PID controllers, high/low detectors, timers, memories set/reset, etc. This organization is represented by means of a network of these components, which communicate information through connections, see figure 9. These networks are organized in a hierarchical way, in the bottom levels there are the basic *elements* like AND, OR, NOT gates, in the middle level we have *diagrams*, and finally in the top level we have *modules*. Then, with a set of *modules*, a DCS was built [4].

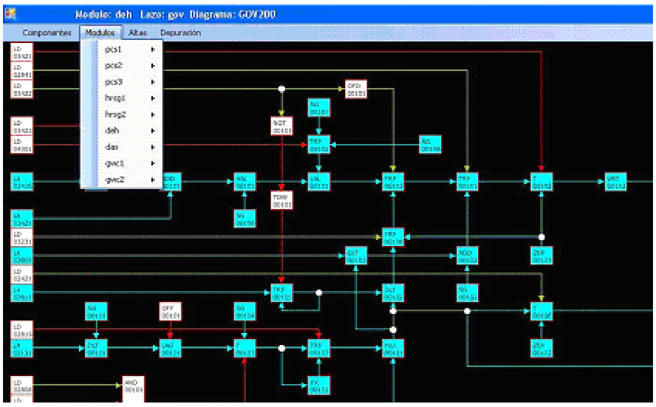

Fig. 9 Control diagram (detail) for speed control on the digital electro-hydraulic control (EHC) system

B. *DCS model for real-time simulation*

The DCS Model was developed with C# programming language, and taking into account the modularization made in the power plant of reference, as shown in figure 9. The main control modules modeled were:

- **pcs1**, Auxiliary Control System, part 1
- **pcs2**, Auxiliary Control System, part 2
- **pcs3**, Electric Network Control
- **hrsg1**, Control of Heat Recovery System Generator, part 1
- **hrsg2**, Control of Heat Recovery System Generator, part 1
- **deh**, Digital Electro-Hydraulic Control System
- **das**, Digital Acquisition System

C. *The Graphic Visualization Tool (GVT)*

The GVT is a software application developed to visualize components in diagrams of the Simulator Control Model.

This tool was very useful during the simulator development and adjustments because it allows to verify and to visualize signals, states, inputs, outputs and parameters of components.
The GVT allows to disable diagrams, modules or components in a way that we can isolate components and to verify its behavior without the influence of all the control model.

D. Processes system

There are 23 different systems process modeled which are the mathematical representation of the behavior of the combined cycle power plant. All models were developed using Fortran Intel$_{TM}$ using a methodology proposed by the IIE, which is summarized in a few steps: a) to obtain and classify process information directly from the power plant; b) to analyze information and to state a conceptual model to be simulated; c) to simplify the analized information to show only the simulated equipments and its nomenclature; d) to justify all possible assumptions; and e) to obtain the flow and pressure network with an operational point, this means at 100% of load. The plant systems were classified, as listed on table 1, into the following common groups:

Table 1 Classified common groups of the plant systems

Group	Systems included
Water	Condensed water, including aerocondenser; HRSG water supply
Steam	HRSG1 & HRSG2 water, HP, IP, and LP steam
Turbine	HP, IP, and LP steam turbine; turbine metals
Electric & Generator	Electric (generator gas U1, U2, and steam unit); primay and secundary regulation for the three generators
Auxiliaries	Auxiliary steam; cooling water; control oil; unit efficiencies; simplified gas turbine; generator cooling air; turbine seal steam; lubricating oil
There is an additional group that contains a set of simplified models with a reduced scope, because their characteristic that it is not necessary to use the complete physical representation.	
Auxiliaries minimized	Chemical's dosage to the cycle water-steam; instrument and service air; HRSG1 & HRSG2 drain; steam drain; chemical analysis; potable water; services water; water of sanitary garbage; demineralized water; common drain; and chemical drain.

V. Conclusions

The SCCC validation is been carried out by CNCAOI specialized personnel under rigorous acceptance simulator testing procedures, and with a lot of experience in the use of simulators, to ensure that this simulator will fulfill the performance specified by the end user in order to have one more useful tool to train the future generation of operators of the combined cycle power plants.

This simulator had several adjustments during its development, because it is expected that its behavior and dynamics will operate similarly to those obtained in the real plant.

An additional aspect that gives a lot of certitude and robustness to the simulator behavior is that this one has the same DCS that the Chihuahua CCPP. 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 Department of Simulation engineers reproduce correctly the real behavior of the reference plant.

The combined cycle power plants have powerful features that include high thermal efficiency, low installed cost, wide range of burning fuels, short installation cycle, compared to conventional thermal, nuclear, and steam plants, as well as low operation costs, it is expected that this simulators will be so strongly claimed for training purpposes in a near future.

VI. Future Works

To standardize the MMI's simulator to Mitsubishi interface view, because it is the real equipment the Chihuahua combined cycle power plant has, so it will be very valuable as well as useful to this power plant trainee operators.

Acknowledgment

The simulators developed by the SD of the IIE have been projects carried out thanks to the effort, enthusiastic and very professional hard work of researchers and technicians of the IIE as well as very good coordination of the co-operation of operators, trainers and support personnel of CFE training center. This project was carried out thanks to the financial support of CFE.

About the SD personnel's labor, it is necessary to mention researchers for their contribution during design steps, implementation and final tests concerning to this simulator: E. Roldán for the coordination of processes modeled implementation; G. Romero for his experience that contribuited in control modeled and M. Salinas for his control system integration; F. Jiménez during his adaptation and adjustments to the steam turbine interface; and L.A. Jiménez involved on simulation sw environment design.

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