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Operator Training Simulators for Geothermal Power Plants

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1. Introduction

The use of real time full scope simulators had proven trough the years, to be one of the most effective and confident ways for training power plant operators. For instance, using simulators the operators can learn how to operate the power plant more efficiently, during a lowering of the heat rate and the reducing of the power required by the auxiliary equipment. A cost-benefit analysis of simulators used at fossil fuel power plants identifies benefits or savings in four categories: availability, thermal performance, component life, and environmental compliance. Specifically in Mexico, in a period of 14 years, the use of simulators for operators training has estimated savings of 750 millions dollars for the power plants (Burgos, E. 1998). Additional benefits using training simulators are: the reliable operation of the power plants is guaranteed, the number of operation faults due human errors is reduced, it can be possible to enable the operation personnel to respond to critical situations as emergency or failures cases, and the efficiency of power plants generation by improvements in its operation is increased. In general, the following problems are present in training centers: high demand of qualified operation personal, necessity of modern systems of qualification that guarantee an integral training with a high degree of quality, and optimize time and available resources.
Otherwise, according to the Mexican Federal Government (2001), Mexico holds third place on a worldwide scale regarding installed geothermal capacity (850MW), more than 2% of the total capacity in the country. It is estimated that the geothermal potential in México, for hydrothermal systems of high enthalpy (temperatures above 180ºC) will allow generate at least 2400 MWe. Some researchers have roughly estimated that hydro thermal enthalpy reserves could produce at least 20,000 MWt.
In the 2000, the *Instituto de Investigaciones Eléctricas* (Electric Research Institute, México, IIE) started a program to equip to the Geothermal Simulation Training Center (CESIGE) of the Federal Commission of Electricity (CFE), with modern training simulators using advanced technologies like modern Human Machine Interfaces (HMI), wireless technology networks, graphical modeling of Control Systems, etc. Thus, in 2000 year, the IIE developed a full scope hard panel simulator of a 110 MW geothermal power plant, see figure 1, executing on a Compaq DS10 Workstation. This geothermal power plant simulator was re-hosted in 2005

and now is executed on a PC network. Also, in the 2005 the IIE developed a Multiple Simulator to be used in classroom, taking as reference the Simulator based on PC network. In 2006 year, the IIE developed a full scope Operator Training Simulator tacking as reference a modern 25MW geothermal power unit, and based on a Distributed Control System (DCS).
In this chapter we present the methodology used to develop the three CESIGE simulators, and the main features describing each one. For example, the full scope 110 MW geothermal power plant simulator has as main goals: to train operators in start-up and shutdown normal plant conditions, to learn how to deal with no normal power plant operation as malfunctions. The Multiple Geothermal Power Plant Simulator is designed to be used on a wireless and local area network, and its main goals are: to improve the assimilation of physical principles, to practice infrequent evolutions, faulted conditions or any operative action, even the user can make an unit start-up from cold to full load conditions, or an unit shutdown. The Multiple Simulator has the same process and control mathematical models than the full scope simulator, thus its precision and reliability in steady states and transients are guaranteed. The multiple and full scope simulators have full compatibility in software and personal computers, thus any modification in the software functions, mathematical models or simulation scenarios, can be upgraded in an easy way in both simulators.
Finally, we present the development of the Full Scope Training Simulator for the *Cerro Prieto IV* 25 MW Geothermal Power Plant. The concept of Full Scope used in this chapter means that the simulator is an exact replica of the geothermal power plant and reproduces its behavior as well, even with the malfunctions simulated. As in the power plant, the simulator is operated from the screens of a Distributed Control System (DCS). The concept of DCS means that the geothermal power plant control is now distributed in Programmable Logic Control Units instead of central control, as control boards, and communicated following the communication system protocol of commercial DCS used in the actual power plant. The simulator models were developed using a standard FORTRAN Intel 9.1 language package, the Human Machine Interface (HMI) was developed using Windows C# package and the control system model was modeled using a Graphical Modeling Control System. This methodology to develop the control system using a translator has as main advantages: high fidelity in dynamics due to the adjustments in process models in order to have the same response as in the actual plant, it allows an accessible and easy way to adjust, to correct and to up grade the control system and process models modifications. The main features and components (process and control modeling, real time software and hardware) of three simulators are described in the following sections.

2. Development of Operator Training Simulators in the Geothermal Simulation Training Center (CESIGE)

The CESIGE aims to train operators of geothermal plants to improve the productivity of these plants. This Center is situated outside of Cerro Prieto Geothermal Power Plants. The initial expectations of the CESIGE have been totally accomplished. Avalos (2005) reports that the Training Center has given a service that represents more than four times the national average of training hours per capita. Also, the yearly goal for the labor achievement certification was overtaken by more than 400%.
CESIGE attends not only all the operation workers of the geothermal power plants in

México (Cerro Prieto, Los Azufres, and Tres Vírgenes), but also it offers a regular training service to Compañía LaGeo of El Salvador, besides other not operation workers of CFE.
According to the statistics from CESIGE, for the Cerro Prieto Power Plants, the number of power plant trips due to human errors and also the percentage of this kind of trips regarding the total numbers of trips have been diminishing through the time since 2000 when the Center began its training program. Avalos (2005) argues that the operational cost of CESIGE is inferior to the cost of the non generated energy because of trips due to human errors (considering only Cerro Prieto Power Plants).

Fig. 1. The 110MW Geothermal Simulator

Certainly a more rigorous procedure is needed to determinate the significance of the training on the improving of the operation performance (historical data, information from other power plants, details of trips, etc.). However these preliminary statistics glimpse a good role of the training on the operational methodologies.

3. General Methodology of Simulation

Generally, the development of Operator Trianing Simulators is a very complex task, because the operator does not have to realize of the differences between the real process and the simulated process, as well as of its operation.The Electrical Research Institute has developed three simulators for the CESIGE between 2000 and 2006 years. These simulators have allowed to CESIGE to be a successful training center in the geothermal domain in Mexico. The methodology used by the Department of Simulation consists basically on the development of two areas: Modelling (process and control models), and a software simulator platform (real time executive program, data bases, graphical tools) developed as own applications.

3.1 The first 110 MW Geothermal Simulator

The plant behavior is simulated by 11 mathematical models that represent the physical systems, and 11 digital and logical control models. The simulated systems are lubrication oil, condensed and circulation water, cooling water, service water, drains, seals steam, gases extraction, services and control air, electric generator, electric network, and steam turbine. The simulation code for all the models were developed by the IIE in FORTRAN 77 language using basic physical principles. So, each mathematical model, is described by a system of differential and algebraic equations, and they were designed to work under a full range of operation. This means from 0% to 100% of load including all the possible transients during an operational session in the actual plant. The control models (divided in logical and analogical controls) were developed using VisSim® tool as a graphical interface and translating the code generated by VisSim into an ANSI C code. The mathematical modeling started with the required design information analysis, followed by the systems functional description, definition of model-model and model-panels interactions, mathematical formulation, codifying and testing to validate the predefined scope. All steady and transient states defined as acceptance tests were carried out. The development and integration methodologies for all the specific areas of the simulator (mathematical modeling, numerical analysis, real time and instruction software, communications and acquisition data system, acceptation tests, model and system integration, documentation, etc.) were designed and implemented by the IIE with support of the CFE. Panels, instrumentation, computers and peripherals were acquired from external providers. The project was divided in four technical stages: 1) Software, 2) Modeling, 3) Local Test, and 4) Final Tests. Figure 1 shows a view of the 110 MW Geothermal Simulator, the first one developed for CESIGE.

4. Re-hosting the 110 MW Geothermal Power Plant Simulator (GPPS)

The original simulator was re-hosted to up-date the hardware and software platforms, thus we will give the implementation details to modernize the original Geothermal Hard Panel 110 MW Simulator

4.1 Original Hardware configuration

The simulator architecture in its Unix version was integrated by 4 computers working on line 3 Work Stations (WS) and 1 PC, and one more Work Station used as backup and software maintenance on the simulator. The first WS on line was the Instructor Console Node where the HMI with two monitors was hosted to control the simulation sessions via the normal simulators functions listed below. The second WS on line was the Real Time Node where the synchronous tasks were executed (mathematical models, real time control of the simulation which may be faster, slower or equal to real time, and synchronism of the global communication of the nodes). The last on line WS was the Input/Output (I/O) Processor that communicated the WS with the hard panels using a TCP/IP protocol on an Ethernet network and controlled the communication between the simulator nodes. The PC on line was in charge to produce the noises and sounds for the control room environment (according the status of the simulated plant, for example, sounds of the circulation pumps when were turned on or off, the sound of the turbine or the sound of the steam valves discharging to the atmosphere). The Geothermal Power Plant Simulator (GPPS) has a control room with 2 hard panels, see figure 1, (with distribution, environment, lighting and process sounds just like the existing in the actual plant control room). The panels-computers communication system had 13 I/O controllers (RTP 6700) that handle 1 analogical input signal, 316 analogical output signals, 341 digital input signals and 805 digital output signals. The original hardware configuration is presented in Figure 2.

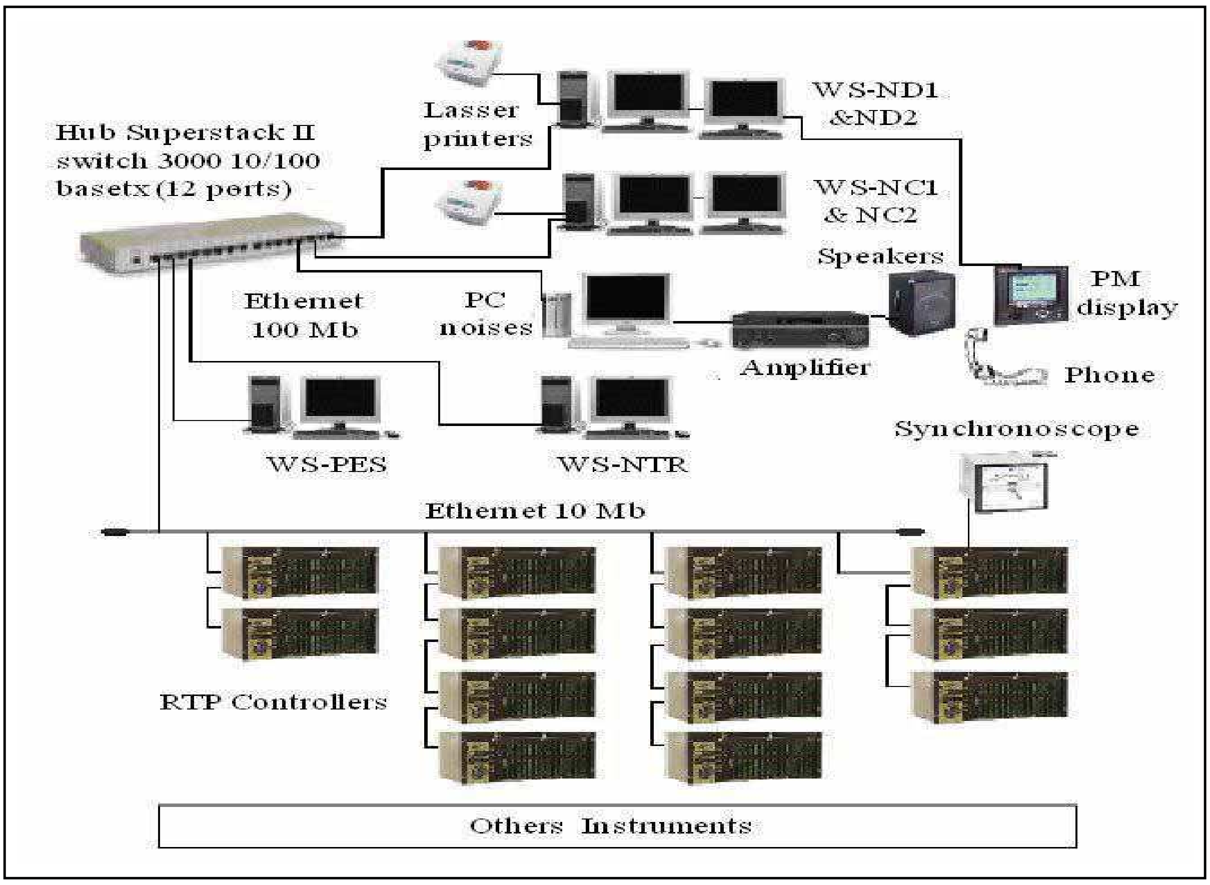

Fig. 2. Hardware Former Configuration

4.2 Original Software configuration

The simulation software environment system consists of a real time executive system, in charge of executing and coordinating the real time tasks, to sequence the dynamic applications (including the instructor console and models programs), to run the program of sounds, and I/O program, the data base and an HMI for the instructor console and interactive process diagrams (DPI).

4.3 Original Models

The algebraic and differential equations of the models were executed sequentially. Each execution second was divided into eight periods of 0.125 sec. Thus, a model could be executed with an integration step of 0.125 sec, 0.25 sec, 0.5 sec or 1 second. The Sequence Matrix (SM) indicates the precedence of execution of the models (scheduler), the integration method and integration step of each model, and the period of execution of each model. The integration step and method were calculated using a multi-step process applied on a transient "difficult to solve" for the mathematical method followed with a proper stability analysis.

4.4 Present Hardware Configuration

Currently, the hardware of the GPPS consists primarily in one PC for the simulation node where the instructor console is installed with two monitors for the simulation control. Additionally, one more PC is used as backup and as testing and development node. The control room is the same existing in the Unix version but some instrumentation was emulated by PC screen displays. The communication system uses the same equipment for the acquisition system but a new program for the I/O driver protocol was designed and implemented. Two more PCs are used to process the information displayed in the screen displays. With these improvements in the instrumentation, the number of signals processed by the I/O cards is 1 analogical input signal, 189 analogical output signals, 341 digital input signals and 805 digital output signals. All these control room and communication features of the GPPS is described by Roldan and Mendoza, (2006). The global new configuration is schematically presented in Figure 3

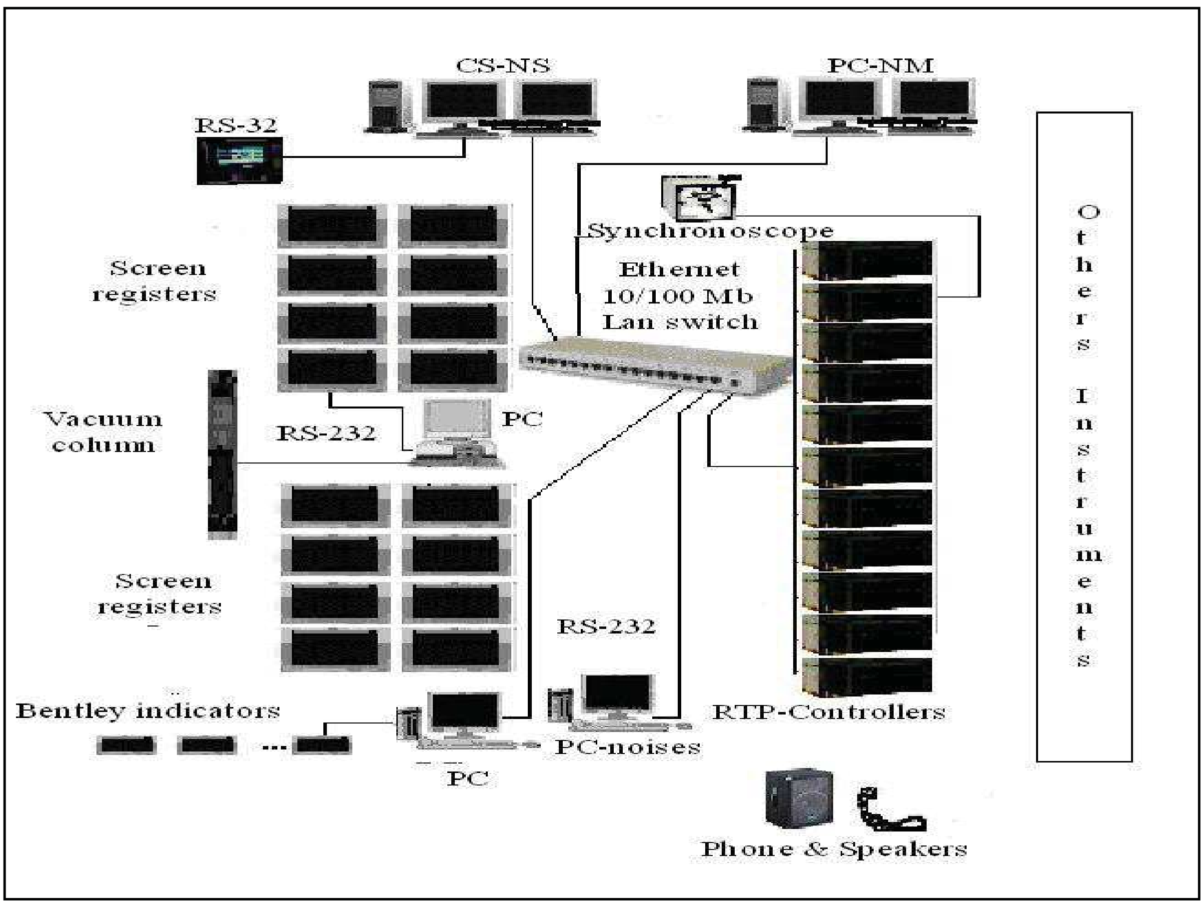

Fig. 3. Hardware Present Configuration

4.5 Present Software Configuration

The software system was completely rewritten on C# language under Visual Studio .Net 2005® and it is based on a real time executive system to synchronize and to control the execution of the different parts of the simulator. The tasks of the executive systems are: to initialize the global structures of the simulator, to coordinate the instructor console functions, to initiate the panel's I/O applications, to activate the DPIs, to execute the models code, and to manage the threads for the sounds and new display instrumentation (Jiménez and Parra, 2005). The instructor console executes the simulator control functions as: simulation status (run, freeze, end of session); establishment of initial conditions; handle of generic and special malfunctions; handle of external and internal parameters; instruments inhibition; plotting of variables; creation of automated training sessions; backtrack; replay; control of speed of simulation (fast time or slow time); training session supervision; hardware override; diagnosis of the components of the hard panels, etc. In the DPI's, developed with Macromedia Flash, not only selected variable values are displayed and dynamic colors changes to show the equipment status, but also malfunctions and actions on specific equipment (pumps, valves, etc.) may be performed with the computer's mouse. Besides, in the standard simulation functions, there exists a program to allow tabulation of variables (for plotting off line) and to monitor or to change of any global variable. The programs of the simulator are communicated using an Access Data Base structure where all the simulator variables are properly organized in order to facilitate both, the communication processes and the simulator's maintenance. All the simulator programs are grouped to form the Simulation Environment, a proprietary program of the IIE (Jimenez *et al*, 2006).

5. The 110 MW Geothermal Power Plant Multiple Simulator

The geothermal multiple simulator (MOST) has a capacity to train from one to six operators simultaneously, each one with an independent simulation session. The sessions must be supervised by only one instructor. The main parts of this multiple simulator are: instructor and operator's stations. On the instructor station, the instructor controls the simulation sessions, establishes training exercises and supervises each power plant operator in individual way. This station is hosted in a Main Personal Computer (NS), see figure 4 and its main functions are: to set initial conditions, snapshots, malfunctions or faults, monitoring trends, and process and soft-panel diagrams. On the other hand, the operators carry out their actions over the power plant simulated on the operator's stations, E01, E02, see figure 4; each one is also hosted in a PC. The main software of instructor and operator's stations are executed on the same NS and displayed in PCs through graphical Interactive Process Diagrams. The advantages of no replica simulators as the MOST presented in this chapter, are described by (Fray, R., and Divakaruni, M.,1995). Besides its lower cost, the authors claim that the use of a single-user compact simulator helps the operators to reduce heat rate by ¼ to ½ percent. Recently it was launched a generic power plant simulator utilizing web technology; this system includes authoring tools and allows practice under the guidance of a virtual instructor or a free-hands mode, see (SIMnews 17, 2003)].

The MOST was designed to be used in a wireless and local area network, and its goals are: to improve the assimilation of physical principles, to practice infrequent evolutions, faulted conditions or any operative action, even the user can make an unit start-up from cold iron to full load conditions, or an unit shutdown. The MOST has the same process and control mathematical models than the full scope simulator, thus its precision and reliability in steady states and transients are guaranteed. The multiple and full scope simulators have full compatibility in software and personal computers, thus any modification in the software functions, mathematical models or simulation scenarios, can be upgraded in an easy way in both simulators.

5.1 Geothermal Multiple Simulator Architecture

Figure 4 shows the MSOT architecture. The Instructor Station resides on a Main Personal Computer, called NS. The NS is a PC with a 1.2 GHz Pentium IV processor, 80 GB hard disk, 1 GB RAM and Windows XP®. This NS executes the most of simulator tasks, it represents the instructor station and works as the trainee's PCs server. The trainee's stations (E01 and E02) are PCs with a 800 MHz Pentium III processor, 20 GB hard disk, 128 MB RAM, Windows XP® and Flash Macromedia® as main software. Each operator or trainee PC executes mainly three tasks: panel of alarms, PC identification software and the display of Interactive Process Diagrams. The local area network is based on a wireless Ethernet communication protocol. With this configuration, the MSOT by now, has capacity for driving up to six operators or trainees simultaneously and it has a capacity to support up to ten operators depending on the hardware acquisitions from CESIGE.

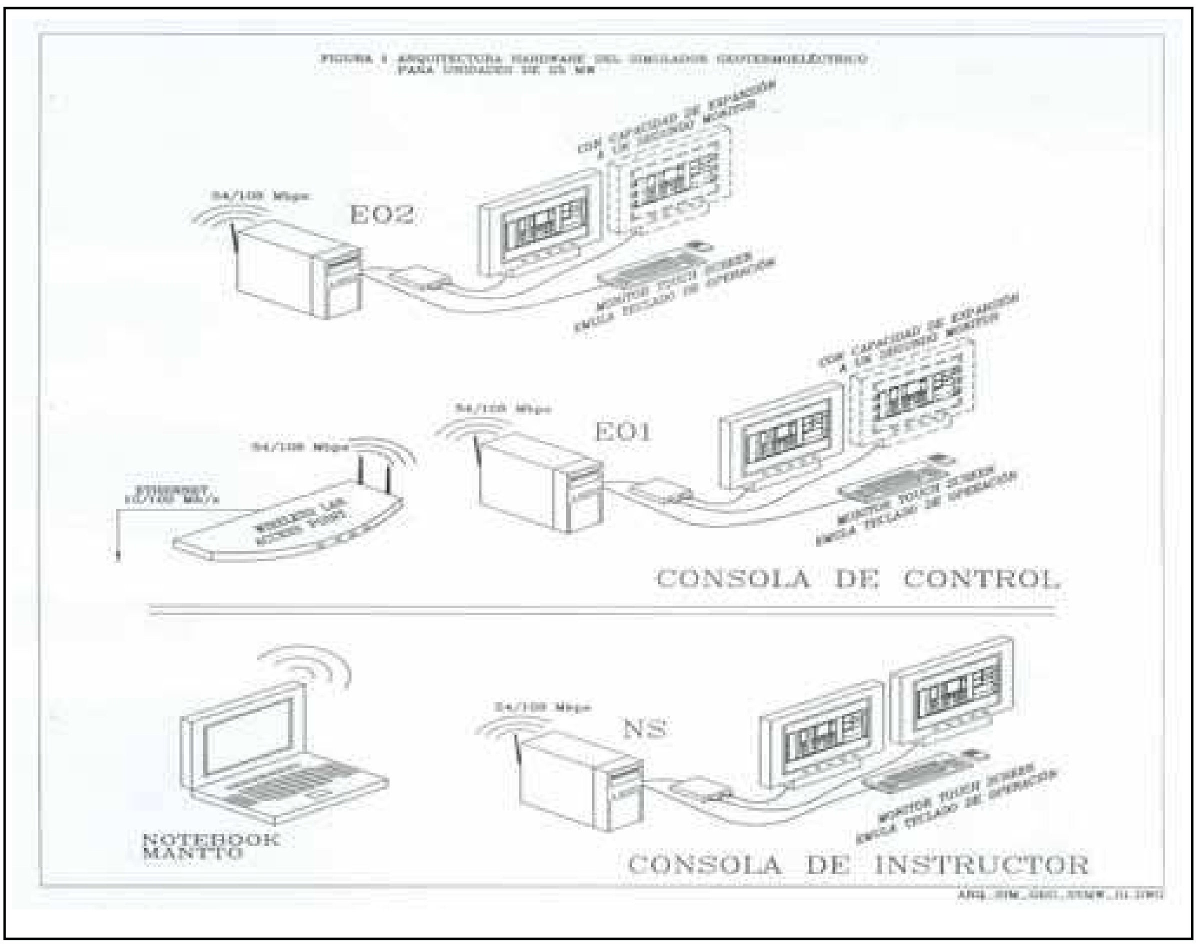

Fig. 4. Geothermal Multiple Simulator (MOST) Architecture

5.2 Instructor Console

The instructor station is a graphic interface used by the instructor to manage the simulation session for each one of the operators, it is entirely executed in the NS. Figure 5 shows a partial view of instructor station monitor. The lower section shows that one operator station will be executed with its process diagrams, and the upper section contains the buttons for sending commands for each one of the simulation sessions. These buttons have the following functions: Control Menu, Initial Condictions menu and Instruction Functions (FAL to introduce malfunctions, INT to introduce internal parametres or local operations, EXT to modify external parametrs as ambiental temperature atmosferic pressure , AUT to introduce automatic exercises, and FET to run the simulator faster/lower than real time).

5.3 Process Monitoring

The instructor has three ways for monitoring the simulation sessions of each trainee: (DPI button to invocate the Operator Console, GRA and MON buttons to invocate graphs and main process monitoring files respectively)

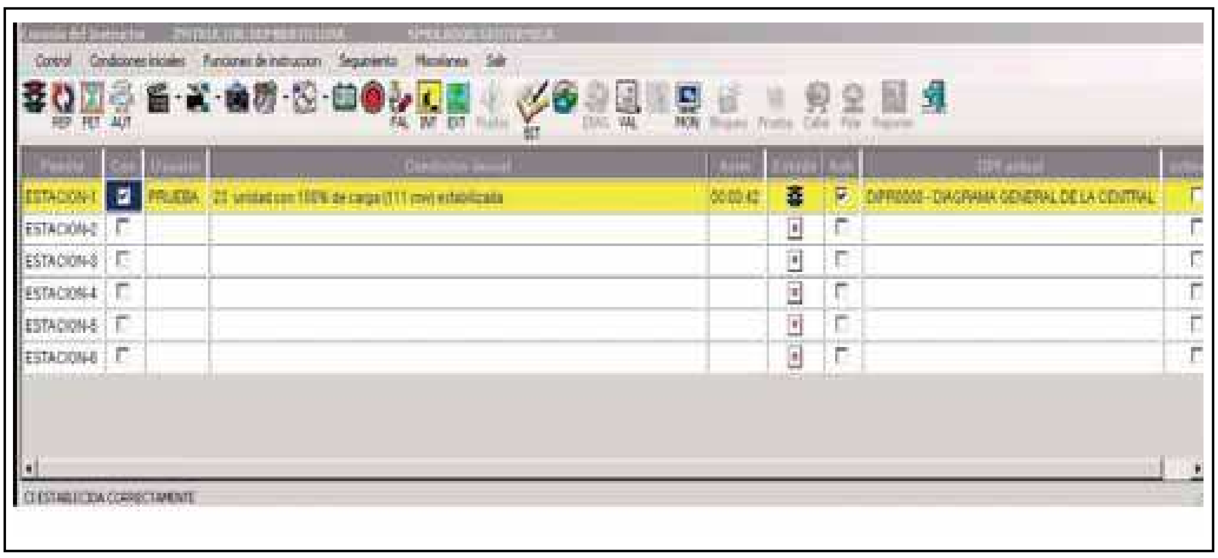

Fig. 5. Geothermal Multiple Simulator Instructor Station

5.4 Operator's Station

The operators carry out their operation actions over the power plant simulated in the operator's stations E01 and E02. The main software of the trainee's stations are executed in NS and displayed in the PCs through the Explorer Navigator. A partial view of a trainee station is shown in Figure 6. In this Figure are distinguished the following sections: (PLANTA shows the Diagram Menu, ALA serves to invocate the Alarm List, JER. VERTICAL shows the Diagram menu in vertical hierarchy , JER. HORIZONTAL show Diagram menu in horizontal hierarchy, SALIR button to exit of the simulation session).

5.5 Geothermal Multiple Simulator Models

The main components of the 110 MW geothermal power plant simulated are: steam station (from geothermal wells), steam dryers, tandem compound turbine, main condenser, vacuum compressors , 20kV electric generator, and services. The mathematical models of the simulator reproduce the behavior of the power plant in any feasible operation state. They are formed by algebraic-differential equations. The mathematical models are divided in two groups: process and control models. The process models represent the main physical

phenomena; they are formulated on the basis of momentum, heat and mass conservation principles. These models are divided in a similar but not identical way like they are in the actual power plant. Examples of modules names are: steam station, main steam, high pressure turbine, cooling water, lube oil and electric network. In order to customizing the modules to the actual power plant, each one of the equipment (i. e. valves, pumps, fans, heat exchangers, stages turbines, etc.), are characterized with design and operation data.
For solving algebraic non-linear equations, the Newton-Raphson methods are used. The differential equations are solved with fixed step-size Euler integration methods. The control

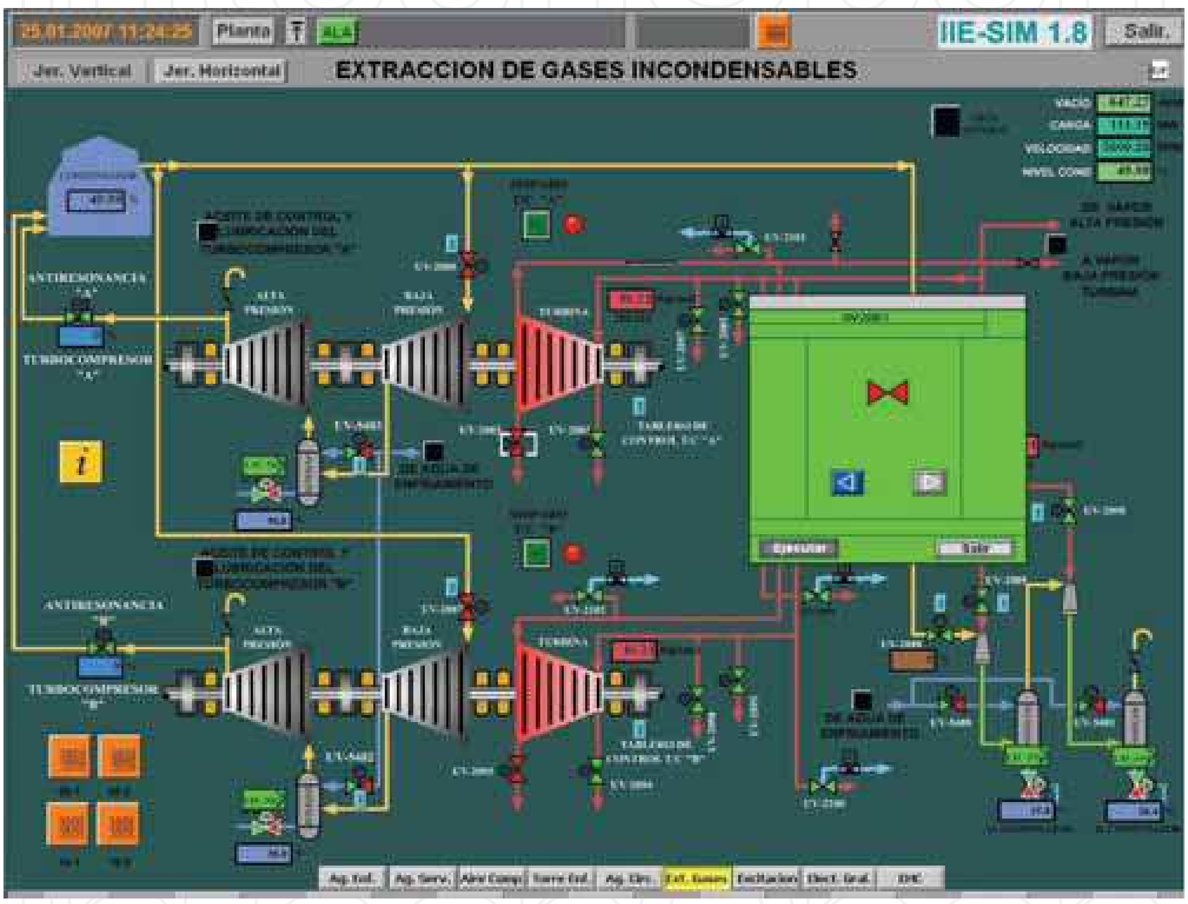

Fig. 6. A trainee screen Interface

models simulate the coordinate control system of the actual plant. These models are organized in: control systems, control groups and design control sheets.
A general task is executed by the control systems, for example, main steam control system and main condenser level control. Control systems are constituted by a set of control groups and each control group does a specific task, for example, MW and turbine speed control and cold water pump subgroup control, etc. The control groups are formed by one or several design control sheets where each one of these sheets has the logic or analogical control loops. The process and control models are solved by a modular sequential approach.
The precision and reliability of the models has been widely tested by the instructors of the CESIGE, (Romero, G. and Salinas, M., 2004), (Patiño et al 2004).

5.6 Validation and Results of the Geothermal Multiple Simulator

A multiple simulator for a geothermal power plant using wireless technology has been described. This simulator was developed and it was designed for being installed in a wireless local area network and can be used from one up to six users simultaneously, each one with an independent simulation session. The sessions must be directed by an instructor. For each operator, the instructor can start each operator's session with the same or different initial condition, can introduce the same or different malfunctions and can ask for different operation actions, with not interference among them. From his station, the instructor can supervise any session with the same monitoring tools available for the users. To accomplish the operation actions required in the simulation session, the trainee has Interactive Process and soft-panels diagrams. These diagrams are fully interactive, and represent the whole simulated plant, so the user can practice any feasible operation, from plant out of service up to full load. The wireless technology, used for first time in our simulators, to connect all PCs in the multiple simulator allows a great flexibility to use it in a typical classroom, in a auditorium, or even near the real geothermal power plant, thanks to its capacity to be moved (Romero G. *et al*, 2008).

6. The 25MW Geothermal Power Plant Simulator.

This section deals with the development of the Full Scope Training Simulator for the Unit 1 of the *Cerro Prieto IV* 25MW Geothermal Power Plant (Romero, G, *et al* 2009). The concept of Full Scope used in this paper means that the Simulator is an exact replica of the geothermal power plant and reproduces its behavior as well, even with the malfunctions simulated. As in the power plant, the simulator is operated from screens of a Distributed Control System (DCS). The concept of DCS means that the geothermal power plant control is now distributed in Programmable Logic Control Units instead of central control, as control boards, and communicated following the communication system protocol of commercial DCS used in the actual Power Plant. The simulator models were developed using a standard FORTRAN Intel 9.1 language package, the HMI was developed using Windows C# package and the DCS was modeled using Graphical Modeling System developed at the Electrical Research Institute.
This methodology to develop the control system using the Graphical Modeling Control System has as main advantages: high fidelity in dynamics due to the adjustments in process models have the same response as in the actual plant, it allows an accessible and easy way to adjust, to correct and to up grade the control system and process models modifications. The following sections describe the simulator architecture, the process models and the Graphical Modeling Control System model used to develop the *Cerro Prieto-IV* 25MW Geothermal Power Plant Simulator.

6.1 Architecture of the Modern 25MW Geothermal Power Plant Simulator

The simulation software, defined by (Jimenez-Fraustro 2005), consists of a real time system dedicated to control and to sequence the different simulator tasks, namely: instructor console, interfaces communication system, mathematical models and the digital control system model. All the software programs are written in *C#* language, the process mathematical models are written in *Fortran* language and the DCS model was developed using a Graphical Modeling System, written also in C#. One of the aims of the project was to have a simulator with a modern hardware-software platform, see (Tavira *et al*. 2008). 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®, DirectX 9.0 and Fortran Intel 9.1.

6.2 Hardware architecture of the 25MW Geothermal Power Plant Simulator

The computer platform of the simulator consists of five Personal Computers interconnected through a fast Ethernet wireless 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 figure 7 shows a schematic of this architecture. The IC station is an instructor console with two 19” monitors, the OC1and OC2 are operator consoles or stations, each one has two 19” monitors; the AD is an auxiliary operator console with two 50” in monitors. The operator can use anyone of the OC1, OC2 and AD for monitoring and controlling any system of the simulated power plant. There is an additional PC, called AC 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 AD stations only use executable versions of the applications Microsoft Visual Studio .Net 2007®.

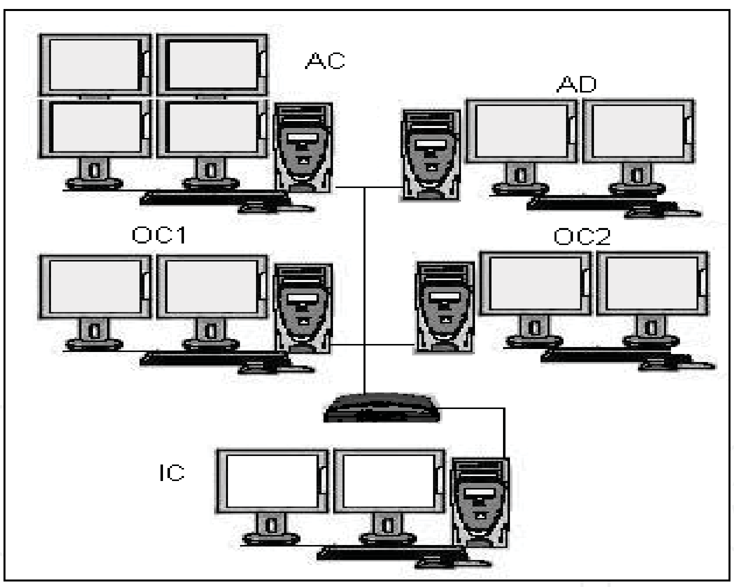

Fig. 7. Architecture hardware of the 25MW Geothermal Power Plant Simulator

6.3 Software applications of the 25MW Geothermal Power Plant Simulator

The software architecture of the simulation environment has three main parts: the real time executive program, the operator module, and the instructor console module, based on the work of (Jimenez-Fraustro, 2005). 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# language, with the exception of the Flash applications. A brief description of each module is shown in the next paragraphs.

Real Time Executive Program. The real time executive coordinates all simulation functions; it is constituted for six modules:
Module 1. Mathematical model launcher. 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.
Module 2, Manager module for interactive process diagrams. 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.
Module 3, Manager module for the global area of mathematical models. It is composed by 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.
Module 4, Manager module for the instructor console. 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.
Module 5, Main module. This module manages all the functions of the former modules.
Module 6, Data base driver. It is devoted to get, of each one of the data base tables, all the required information by the executive system

6.4 The 25MW Geothermal Power Plant Simulator Process Models

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 iron 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 were a single executable program. The plant process is divided into three groups: the first group simulates the main systems as Turbine, Steam, an Condensation, 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: 1.- Main Turbine, Main Steam, Main Condensation System, Electro-hydraulic Control System. 2.- Auxiliary Systems as Vacuum System, Lube and Control Oil system, Gland Steam, Air instrument and Services, , Turbine Mechanics (Vibration and Supervisory System), and 3.- Electrical System, Excitation, Generator and Cool Generator System.

6.5 The Control System Graphical Modeling

This part is composed by three sub-systems: a) The dynamic constructor of control models, b) the Data Base Handler and c) the Graphic Visualization tool.

The *dynamic constructor of control models* have as main tasks: to complete the integration of data and functions (a software component consists in different values (states) and the functions that process these data). To build the libraries to analogical and logic components, (like PID controllers, logical gates, timers, etc.). To organize the component execution sequence, in order to avoid indeterminations. Instances of components inter-connected by mean of their input/output ports. To create structures in order to store component states and to have asynchronous initial conditions. To encapsulate components in order to hide details of implementation for users. Identity: each instance of a component has a unique identity. Polymorphism: the interfaces are described outside software implementation in a way that a code that requires an interface can use any component/object. This allows a great flexibility in the application design. The *Data Base Handler* consists of the control of component data base arranged as a hierarchical design. The control component data base has 340, 000 components and we have to implement algorithms to store and to recuperate information from data base in an optimal and efficient way. And *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. In figure 8, we show a diagram as it is visualized with the GVT and that were obtained from control diagrams using the Graphical Modeling Control System developed by the Electrical Research Institute. In this figure we see and test, for example the *high selector* component.

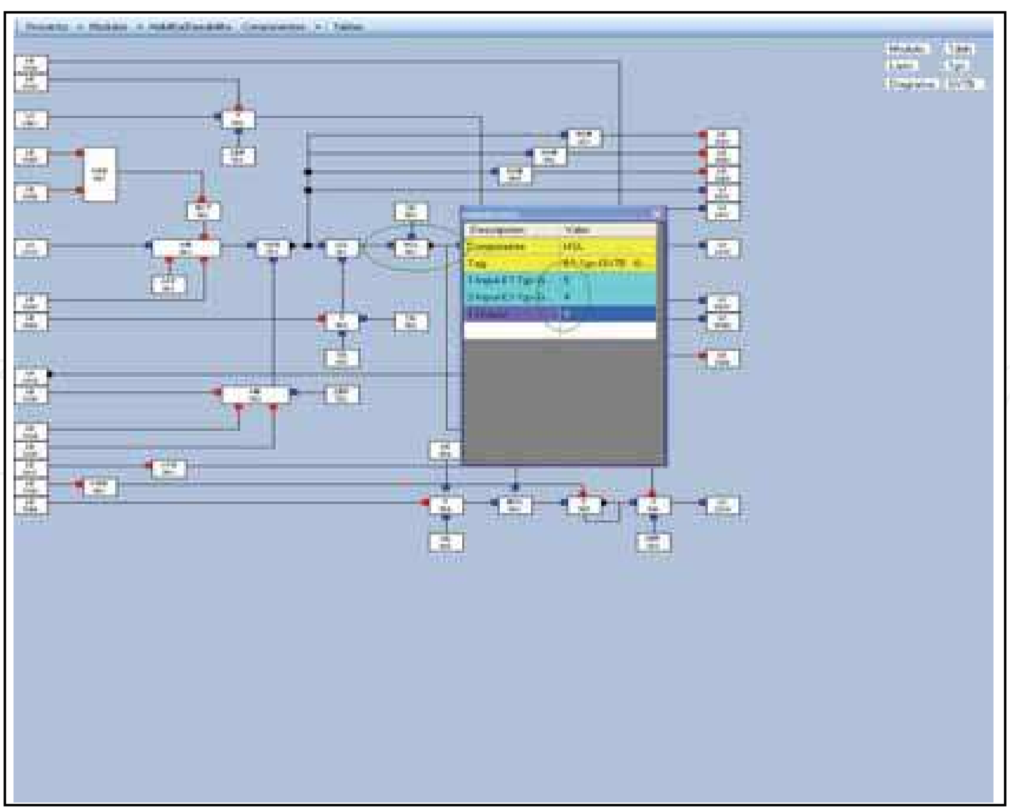

Fig. 8. A diagram of the DCS visualized with GVT

6.6 The Distributed Control System Interface

The replica of the DCS interface showed in figure 9, was developed following (Yamamori, 2002), in the Microsoft.NET platform using as programming language the oriented object Microsoft Visual C# 2005. Using personalized user controls, each control has its grade states and they generate events for activation of the main control, associated to each device. The DCS interface was developed taking into account 5 sub-systems, as follow:

The *Component Editor* defines the main characteristics for each element that integrates the control loop. We defined 9 elements that may constitute a control loop, be analogical or digital. The *Device Editor* defines the characteristics of devices used in control screens, like pumps, valves, displays, ventilators, switches, own methods in order to up. The *Emulated Keyboard* constitutes a fundamental device in the simulator for device operation from control loops in the control screens and for navigation options through control screens. This application emulates the real specialized keyboard for the geothermal plant operation, and can be personalized according system requirements. The *Diagram* and *Control Loop Viewfinder* take in charge of the dynamic generation from the XML files configuration of control screen dynamic instances, the communication with real time executive system software, the navigation and sub-system activation like alarms, events, tendencies, trip sequences, etc. The *Tendency Viewfinder* is in charge of of the configuration of tendency groups, where we define the signals and monitoring frequency.

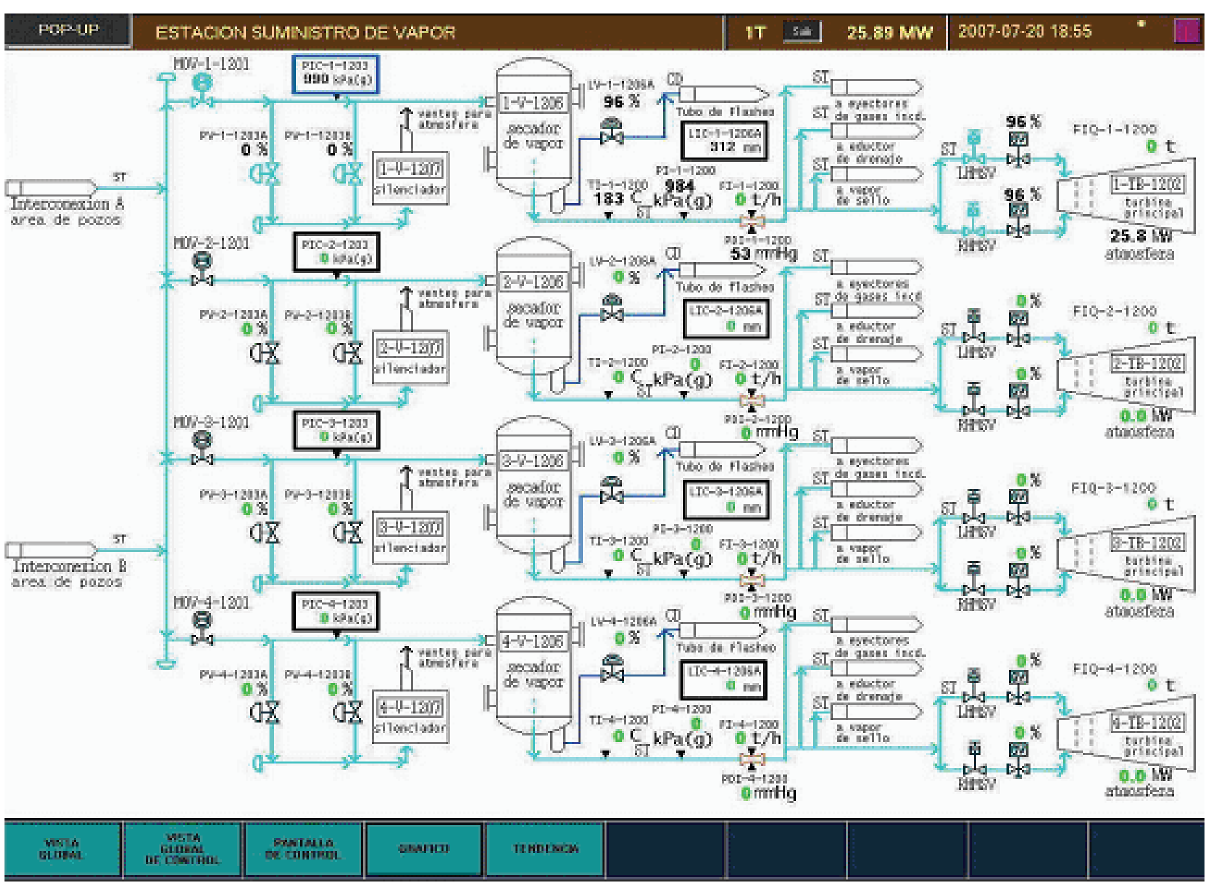

Fig. 9. Control Interface of Main Steam System

6.7 Validation and Result

The *Cerro Prieto-IV* 25 MW Geothermal Simulator validation was carried out proving its response against the 12 operation procedures elaborated by CESIGE-CFE specialized personnel, denominated "Acceptance Simulator Test Procedures", (Romero G. 2006). This validation has as primary targets: to verify that the simulator accomplish satisfactorily the operation conditions from cold iron to 100% of load; to satisfy the steady states of 25, 50, 75 and 100% of the nominal capacity; to verify 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 iron to 100% conditions. For example, Figure 10 and 11 show the trends of some critical variables in the *Cerro Prieto-IV* Simulator for Manual and Automatic geothermal power plant Start-up operations; the trnds of all the variables are according to the expected values

Fig. 10. *Cerro Prieto-IV* 25 MW Goethermal Simulator, Manual power plant Start-Up

7. Conclusions

The Electrical Research Institute (IIE) has equipped CESIGE with three simulators using the top technology developed by the same IIE. These simulators are functional and have a 99% of availability to train operators. The 110 MW Geothermal Power Plant, the Multiple 110 MW Power Plant and the 25MW Cerro-Prieto IV Geothermal Power Plant simulators were developed entirely by the IIE, developing own tools where the most important is the IIE

generic software environment platform taken as a basis to develop these simulators, as well as other ones.
The main results show that CESIGE cover all training necessities and have additional capacity to train other operators from external geothermal power plants (form example, from Republic El Salvador). New software applications were developed to accomplish the simulators development: a new model of the Distributed Control System, based on Graphical Modelling Tools, having finally in the simulators exactly the same actual plant dynamics responses, as is showed in figures 10 and 11.

The future research is focused on the improvement in tasks that we still do in a manual way, for example TRANSDUC application that links process models with DCS model, we use a list of digital/analogical inputs/outputs to feed the control system, we complete that list and we generate a software application to be executed by the executive program, and we want to improve this task, executing the TRANSDUC application as a part of the control graphical modelling of the DCS.

Fig. 11. *Cerro Prieto-IV* 25 MW Goethermal Simulator, Automatic power plant Start-Up

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The techniques of computer modelling and simulation are increasingly important in many fields of science since they allow quantitative examination and evaluation of the most complex hypothesis. Furthermore, by taking advantage of the enormous amount of computational resources available on modern computers scientists are able to suggest scenarios and results that are more significant than ever. This book brings together recent work describing novel and advanced modelling and analysis techniques applied to many different research areas.