Proceedings of the 2009 Winter Simulation Conference
M. D. Rossetti, R. R. Hill, B. Johansson, A. Dunkin and R. G. Ingalls, eds.

DEVELOPMENT OF A 25MW GEOTHERMAL POWER PLANT FULL SCOPE SIMULATOR BASED ON A CONTROL SYSTEM GRAPHICAL MODELING

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ABSTRACT

This paper describes the development of an Operator Training Simulator (OTS) for the Geothermal Training Simulation Center (GTSC) of the Mexico's Federal Commission of Electricity (CFE). The Department of Simulation (DS) of the Electrical Research Institute (IIE) developed this simulator using as reference the Unit IV of the Geothermal Power Plant *Cerro Prieto*, located at the north of Mexico. The *Cerro Prieto 25MW* simulator was finished and delivered to GTSC in June 2007. This simulator is a high-fidelity real time dynamic simulator built and tested for accurate operation over the entire load range. The *Cerro Prieto-IV* simulator is a replica of the real power plant thanks to main characteristics of the Graphical Model of the Distributed Control System (DCS), and was used primarily for operator training although it has been used for procedure development and evaluation of plant transients.

1 INTRODUCTION

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 180^{o}C) will allow generate at least 2400 MWe. Some researchers have roughly estimated that hydrothermal of low enthalpy reserves could produce at least 20,000 MWt. The original reference plant of the developed simulator, the Unit 10 of Cerro Prieto IV Generation Center produces 25 MW and all Units produce in total 100MW. The GTSC, is devoted to train CFE operators of geothermal power plants. For satisfying the CFE training requirements, the GTSC has: simulators based on control boards see (Tavira 2001) , classroom simulators and recently, simulators based on HMI multi-window. A wide list of the main benefits in using a variety of training simulators is described by the IAEA-1998, some of the most important are: the ability to train on malfunctions, transients and accidents; the reduction of risk 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 the Full Scope Training Simulator for the Unit 1 of the *Cerro Prieto IV* Geothermal Power Plant. 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 DCS. The concept of DCS means that the geothermal power plant control is now distributed in Programmable Logic Control Units instead off central control, as control boards, and communicated following the communication system protocol of commercial DCS used in the real Power Plant. The simulator models were developed using a standard FORTRAN Intel 9.1 language package, the MMI 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 the adjustments in process models to have the same response as in the real 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 Simulator.

2 SIMULATOR ARCHITECTURE

The simulation software, defined by (Jimenez-Fraustro 2005), consists of a real time system dedicated to control and sequence the different simulator tasks, namely: instructor console, interfaces communication system, mathematical models and the control model system, based on the Graphical Modeling System . 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.

2.1 Hardware Architecture

The computer platform of the simulator consists of four 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 1 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 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.

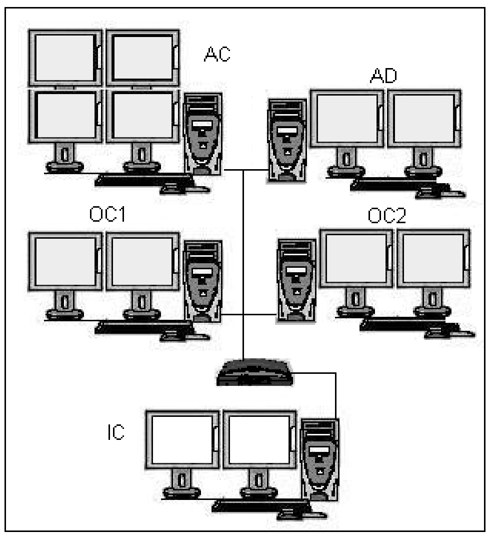

Figure 1. Simulator Architecture

2.2 Software Applications

The software architecture of the simulation environment has three main parts: the real time executive, 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#, with the exception of the Flash applications. A brief description of each module is shown in the next paragraphs.

2.3 Real Time Executive Program

The real time executive coordinates all simulation functions; it is constituted for six modules:

- **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.

- **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.
- **Manager module for the global area of mathematical models**. 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.
- **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.
- **Main module.** This module manages all the functions of the former modules.
- **Data base driver**. It is devoted to get, of each one of the data base tables, all the required information by the executive system

3 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 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 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.

4 CONTROL SYSTEM GRAPHICAL MODEL

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

The *dynamic constructor of control models* have as main tasks:

- 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*

- The control component data base has 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.

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 2, 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.

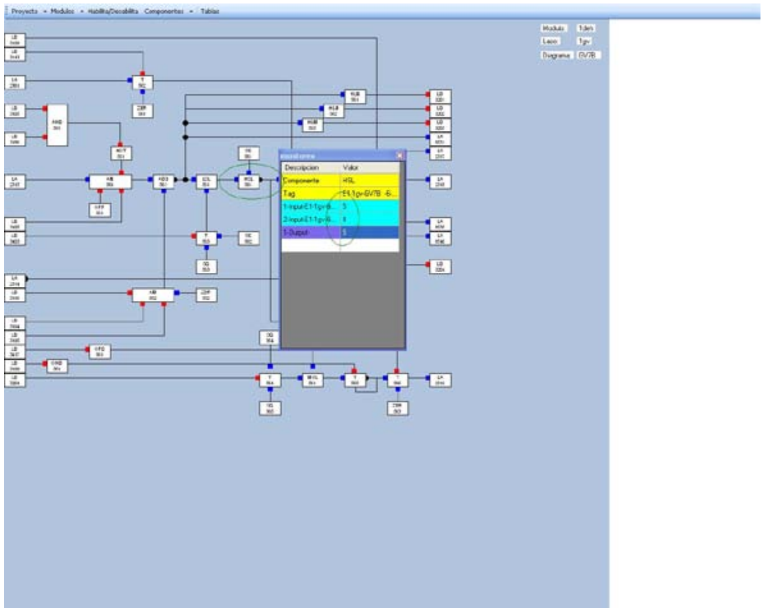

Figure 2. A diagram of the DCS visualized with GVT.

5 DCS INTERFACE

The replica of the DCS interface showed in figure 3, was developed following (Yamamori, 2002), in the Microsoft.NET platform using as programming language the oriented object Microsoft Visual C# 2005 etc. Using personalized user controls, each control has its grade states and to generate events for activation of the main control, associated to each device.
software. 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* are charged of the dynamic generation from the configuration XML files 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 charged of the configuration of tendency groups, where we define the signals and monitoring frequency.

6 VALIDATION AND RESULTS

The *Cerro Prieto-IV* Simulator validation was carried out proving its response against the 12 operation procedures elaborated by GTSC-CFE specialized personnel and based on real tendencies from Unit IV of Cerro Prieto Geothermal Power Plant. These operation procedures are denominated “Acceptance Simulator Test Procedures”, and the final results are presented in (Romero G. 2006). This validation was carried out always taking into account the real behavior of main variables like, Electrical Power, Inlet Steam Temperature, Turbine Speed, Position of Governor Valves, in normal and faulted conditions. The real behavior of main variables was done by the Cerro Prieto, Unit IV engineering departments.

The validation also had 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. For example, Figure 4 and 5 show the tendency of some critical variables in the *Cerro Prieto-IV* Simulator for Manual and Automatic geothermal power plant Start-up operations; in cyan color the tendency of the main variable for Power's behavior, in green and blue colors, the tendency of Turbine Pressure variable following the increase of power.

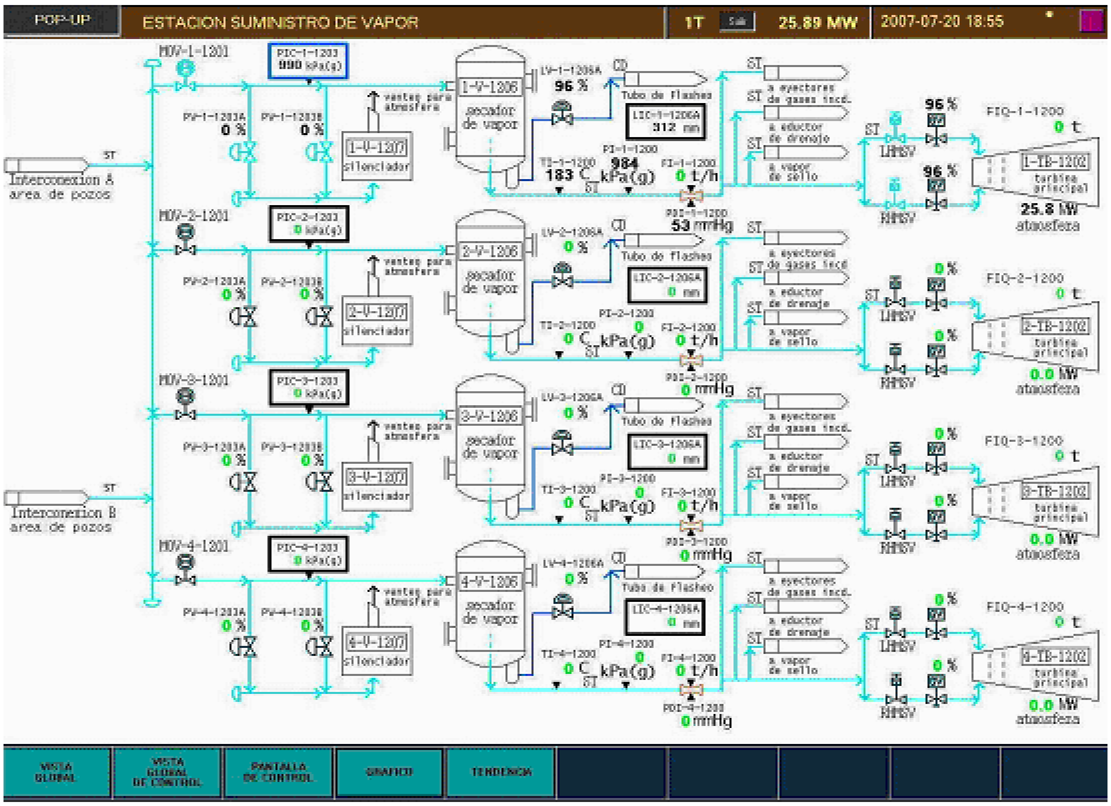

Figure 3. Control Interface of Main Steam System

7 CONCLUSIONS

The Simulator of the geothermal power plant *Cerro Prieto-IV* is a high-fidelity, plant specific simulator for operator training. Realism is provided the use of extensive DCS screens emulation. This simulator is used for training of CFE Geothermal Unit IV power plant operators. It was tested and validated by CFE personnel who have a lot of experience in the geothermal 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 operation plant, thanks mainly to the Graphical Modeling Control System. 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 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.

Figure 4. *Cerro Prieto-IV* Simulator . Manual power plant Start-Up

Figure 5. Simulator of Cerro Prieto IV, Automatic Start-Up of the power plant

ACKNOWLEDGMENTS

This project was supported by the CFE. The authors would like to thank all the personnel of the IIE and CFE who participated during the project development, especially Humberto Luna for their support for carrying out the operation tests.

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