

# 110 MW Geothermal Power Plant Multiple Simulator, Using Wireless Technology

Guillermo Romero-Jiménez, Luis A. Jiménez-Fraustro, Mayolo Salinas-Camacho, and Heriberto Avalos-Valenzuela

**Abstract**—A geothermal power plant multiple simulator for operators training is presented. The simulator is designed to be installed in a wireless local area network and has a capacity to train one to six operators simultaneously, each one with an independent simulation session. The sessions must be supervised only by 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) 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; 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 (IDP). The geothermal multiple simulator has been installed in the Geothermal Simulation Training Center (GSTC) of the *Comisión Federal de Electricidad*, (Federal Commission of Electricity, CFE), Mexico, and is being utilized as a part of the training courses for geothermal power plant operators.

**Keywords**—Geothermal power plant, multiple simulator, training operator.

## I. INTRODUCTION

THE use of real time full scope simulators had proven through the years, to be one of the most effective and confident ways for training power plant operators. 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 [1]. A cost benefit analysis of simulator used at fossil fuel power plants identifies benefits in four categories: availability savings, thermal performance savings, component life savings, and environmental compliance savings, [2]. 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, following [3]. In general, the following problems are present in the 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.

In the 2000, the *Instituto de Investigaciones Eléctricas* (Electric Research Institute, México, IIE) developed for the Geothermal Simulation Training Center, a full scope hard panel simulator of a 110 MW geothermal power plant, executing on a Compaq DS10 Workstation, [4]. This geothermal power plant simulator has been upgraded in 2005 and now is executed on a PC network. In the 2003 and 2004, the IIE developed two multiple simulators or no replica simulators for 300 and 350 MW fossil power plants respectively, [5]. These projects were done in Mexico for the *Centro Nacional de Capacitación y Adiestramiento de Operadores, Ixtapantaongo* (National Training Center for Operators) of the CFE.

The advantages of no replica simulators as the multiple Geothermal Power plant simulator presented in this paper, are described by [6]. Besides its lower cost, the authors claim that the use of a single-user compact simulator helps the operators to reduce heat rate by  $\frac{1}{4}$  to  $\frac{1}{2}$  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, [7].

In this paper we present the main features of a multiple simulator of a 110 MW geothermal power plant, which is designed to be used in a wireless and local area network, and its goals are: improve the assimilation of physical principles, 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.

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## II. MULTIPLE SIMULATOR FOR OPERATOR'S TRAINING (MOST)

The multiple simulator for operators training (MSOT) is installed in a classroom (local area network) as a complement of the training courses for operators of geothermal power plants. From his station the instructor has the control of the simulation sessions from one to six operators or trainees simultaneously. Through his station, the instructor establishes the same or different training exercises for each one of the operators and supervises them in an individual way. On the other hand, each operator has his station for operating the power plant that is simulated in an independent way from other operators.

The scope, functions and man-machine interfaces of the MSOT were exhaustively revised by the instructors of the GSTC, in order to accomplish their training requirements.

The main features and components of the MSOT are described in the following sections.

### A. Multiple Simulator Architecture

Fig. 1 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, represents the instructor station and works as the trainee's PCs server. The trainee's stations (EO1 and EO3) 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 simultaneously until six operators or trainees and has a capacity and it is prepared to support until ten operators depending on the hardware acquisitions from GSTC.

All PC's, NS and EO1, EO2 are interconnected by a wireless LAN-Switch through wireless communication cards

The wireless LAN-Switch is a 3Com, 3CRW875075A model, it has 1 port for wire connection to 10/100 Mbps. Wireless communication speed to 54/108 Mbps and we can connect until 128 users at the same time. It has a communication ratio of 50 meters for transmission and reception when we use 108 Mbps, and a ratio of 100 meters when we use 54 Mbps.

### B. Instructor Station

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. Fig. 2 shows a partial view of instructor station monitor. The lower section shows that one operator station will be executed with his 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:

#### 1) Control menu

The Control Menu or button has three options:

**Run mode.** This function starts a dynamic simulation of the power plant. The mathematical models of the control and process respond to the actions of the student in a very close way as it happens in the actual plant. The simulator is executed in real time.

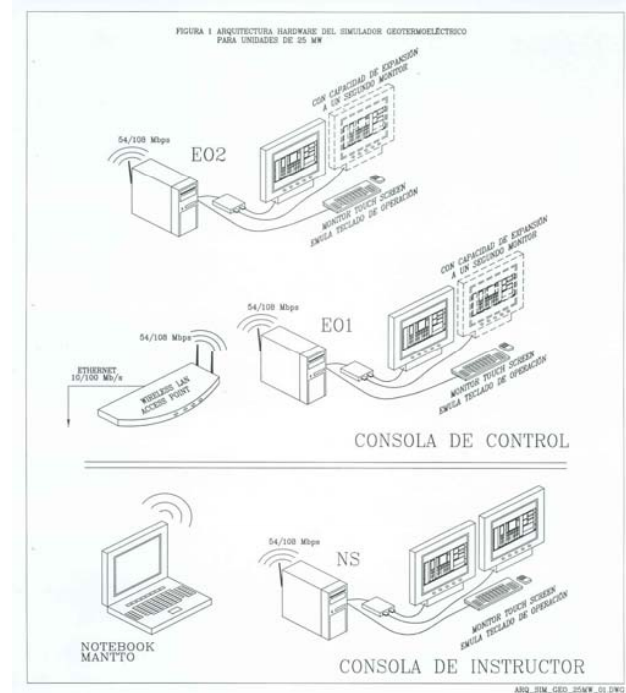


Fig. 1 Multiple simulator architecture (MOST)

**Freeze mode.** This function stops the simulation session until the instructor returns to the Run mode.

**Step by step mode.** This function allows to simulate models step by step. The minimum step is 0.1 seconds.

#### 2) Inicial Conditions Menu

With the menu of Initial Conditions the instructor can select an initial condition for beginning the simulation session. There are more than 200 and they are grouped according to the available instructors in the training center. The initial conditions include from power plant out of service up to full load. The instructor can record a new initial condition (snapshot) or erase an old initial condition. And he can specify the time interval for getting automatic snapshots.

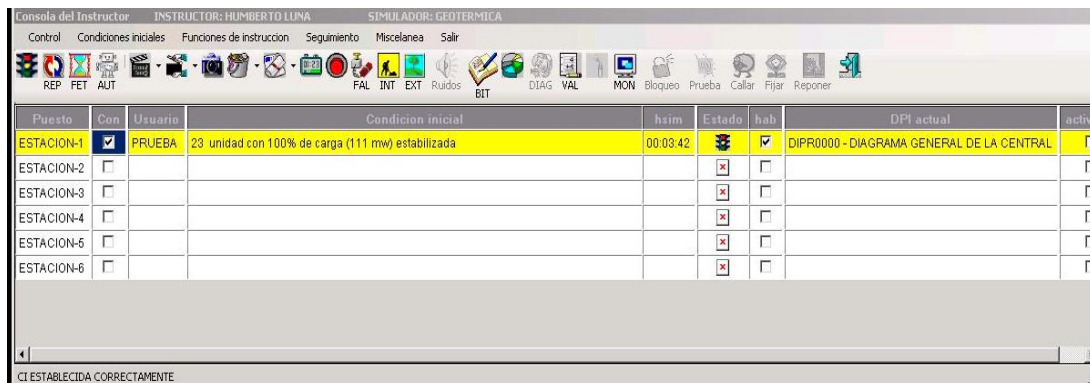


Fig. 2 Instructor Station

### 3) FAL button

Instructor uses the FAL button for introducing/removing an equipment malfunction in any moment of the student simulation session. There are 140 generic malfunctions. Examples of them are: pumps trips, heat exchanger pipes break with up to 100% severity, obstructed control valve and false control signal. All the malfunctions are grouped in systems and subsystems for an easy localization.

### 4) INT button

With the INT button the instructor simulates the operative actions that are not related with automatized equipment. These operative actions are associated with the local actions that are performed in the actual plant, by an auxiliary operator. The MSOT has 40 of these actions, examples of them are: open/close valves or switches and on/off pumps or fans. In a similar way as the malfunctions, they are grouped in systems and subsystems.

### 5) EXT button

EXT button permits to the instructor modify the external conditions that are related with the process. These conditions are: atmospheric pressure, room and sea water temperatures, voltage and frequency of the system.

### 6) AUT button

The instructor uses this button for creating training exercises with a fixed sequence. Each one of the exercises can include: initial conditions, malfunctions, local actions, and a time sequence defined by the instructor. The exercises are stored for its subsequent use.

### 7) FET button

This button allows the instructor to modify the simulation time until 10 times faster or lower with respect to real time.

## C. Process Monitoring

The instructor has three ways for monitoring the simulation

sessions of each trainee:

### 1) IDP button

It displays in the instructor station a submenu with the process and soft-panels diagrams. The process diagrams display the pressures, flows and temperatures dynamically for the major equipments and process streams. Also show if a valve is open (red color) or closed (green color), or if a pump is on (red color) or off (green color). These diagrams cover the whole power plant simulated (i.e. auxiliary systems, electric services, steam source, generator, turbine and condensate water).

### 2) GRA button

It gives to the instructor a trend window, where he can select the required process variables for supervising the simulation session.

### 3) MON button

It pop ups a monitoring window where the instructor selects a group of variables for monitoring its value. In this way, when the instructor click these buttons he gets a copy of the actual state of the simulation session of any trainee. See Fig. 3.

NUM.	VARIABLE	DESCRIPCION
303.7439	ATMOSFERA(I,I)	Temperatura del flujo de agua de enfriamiento a enfriadores
306.74045	APROBADA(I,I)	Flujo de agua de enfriamiento por bomba A
1.52	ALIMENTA(I,I)	Nivel del tanque de aceite del TO
1607790	ALTAJETA(I,I)	Presión de descarga de bomba principal
1535196	ALTAJETA(I,I)	Presión de entrada a la turbina hidráulica
305.8613	ALTAJETA(I,I)	Temperatura de dren de aceite de chumacera 1 del TO
23.39317	ALMACEN(I,I)	Flujo de aceite de lubricación
1.673796	CONSUMO(I,I)	Masa de aire en el condensador
1.497249	CONSUMO(I,I)	Nivel del condensador
15023.98	CONSUMO(I,I)	Presión total del condensador
303.7464	CUTREPA(I,I)	Temperatura a la salida de la piletta de la torre de enfriamiento
322.1132	CUTREPA(I,I)	Temperatura del agua en el condensador
6449.273	CONSUMO(I,I)	Flujo del agua de la torre de enfriamiento
6755.708	CONSUMO(I,I)	Flujo del agua a la torre de enfriamiento
277825	EXPANSA(I,I)	Presión de aceite de lubricación
315.5233	EXTINGUI(I,I)	Temperatura de aceite de salida del enfriador
328.9675	EXTINGUI(I,I)	Temperatura de aceite de chumacera 1 de TC A
303.7968	EXTINGUI(I,I)	Temperatura de líquido en postcondensador
4.238037E-05	EXTINGUI(I,I)	Vibración de chumacera 2 de turbocompresores A
0.7556	EXTINGUI(I,I)	Flujo de vapor condensado de alta presión
52.22967	EXTINGUI(I,I)	Flujo total de drenaje al condensador principal
3.579964	EXTINGUI(I,I)	Flujo de extracción de incondensables
1.111975E+08	EXTINGUI(I,I)	Potencia eléctrica generada

Fig. 3 Monitoring of the Process

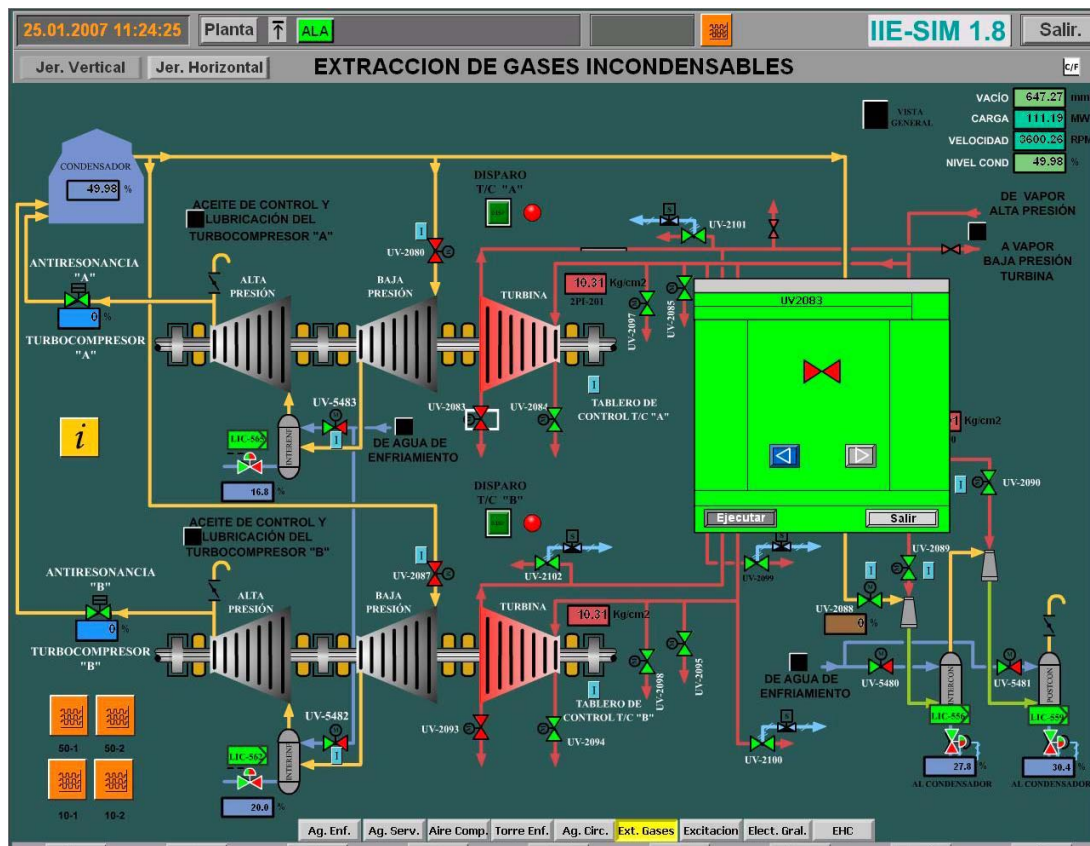


Fig. 4 A trainee screen interface

#### D. Operator's Station (E01 and E02)

The operators carry out their operation actions over the power plant simulated in the operator's stations. 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 Fig. 4. In this Figure are distinguished the following sections:

##### 1) PLANTA button

It is the main menu that allows the operators to navigate in all Interactive Process Diagrams. It is a fixed button and can be invoked any time.

##### 2) ALA button

It allows to the operator invoke the Alarm Information System.

##### 3) JER VERTICAL button

It allows the operator to display diagrams related with the same system in vertical order.

##### 4) JER HORIZONTAL button

It allows to the operator display diagrams related with the same system placed in horizontal order.

##### 5) SALIR button

It allows to the operator to get out the simulation.

The inclusion of operative actions related with the local actions ("blue buttons" in Fig. 4 as the INT button for the instructor station) is an additional feature in these diagrams. In this way, an advanced operator can locate and perform his local actions required, while a beginning operator can ask to the instructor about the performance of the actions in the instructor station. Therefore, the process and soft-panel diagrams are the main tool for the trainees to practice any operation mode. This includes steady and transients states and operative actions as: steam lines heating, condenser vacuum, turbine running, electric generator synchronization, or required operation actions due to malfunctions introduced by the instructor.

#### E. Mathematical Models

Briefly, 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 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 GSTC, [8], [9].

#### F. MSOT Implantation

The mission of the Geothermal Simulation Training Center is to train and to qualify in technical and operative subjects to the operators of the Geothermal Power Plants of the Federal Commission of Electricity. In this Center, the MSOT has been installed in a classroom to be used by six trainees. Other four trainees are available through the local area wireless network, and they can be used for the instructors for preparing scenarios or exercises for their training sessions. Before the MSOT implantation, a typical training session consisted of classroom session, where an instructor taught the theoretical subjects of the power plant and after that, the operator practices his knowledge in the full scope hard panel simulator.

Nowadays, when we use the MSOT, the classroom session is enhanced because the theoretical subjects may be related with predefined simulation exercises, each trainee must perform the operative actions required in his station and this promotes a better understanding of the subjects by the operators. Even more, because the MSOT is a full scope simulator, the operators can practice infrequent evolutions, fault conditions or a unit start-up from cold to full load conditions.

### III. CONCLUSION

A multiple simulator for a geothermal power plant using wireless technology has been presented. This simulator was developed and it is designed for being installed in a wireless

local area network and can be used for one 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 scope of the mathematical models and the instruction functions were exhaustively validated by the instructors of the GSTC, in order to accomplish their training requirements.

The wireless technology, used as a first time in our simulators developed, 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 carried practically anywhere the personnel of the GSTC decides.

The multiple simulator has been installed at the GSTC of CFE, this training tool allows to increase the training hours of the operators via simulation, for improving the assimilation of physical principles and for practicing any operative action, and at the same time, making more efficient the training with hard panel simulators.

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