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# Evolution, Tendencies and Impact of Standardization of Input/Output Platforms in Full Scale Simulators for Training Power Plant Operators

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***Abstract*—**This article presents the evolution and technological changes implemented on the full scale simulators developed by the Simulation Department of the Instituto de Investigaciones Eléctricas[1] (Mexican Electric Research Institute) and located at different training centers around the Mexican territory, and allows US to know the last updates, basically from the input/output view point, of the current simulators at some facilities of the electrical sector as well as the compatible industry of the electrical manufactures and industries such as Comisión Federal de Electricidad (CFE[*], The utility Mexican company). Tendencies of these developments and impact within the operators' scope are also presented.

***Keywords*—**Control room, communication protocol, instructor console, modeling, controller, training simulator.

## I. Introduction

THE Mexican Electric Research Institute (IIE) since its foundation on 1975 has been the right hand as R&D institution of the Mexican electrical utility offering technical innovations. Within the Simulation Department (SD) and among other activities, it has also developed, installed, and integrated computer software systems and equipment in order to put on service and support new computer platform of simulators for training personnel that operate control rooms of the electrical company. Some full scale simulators developed are presented, the evolution of its hardware (hw) and software (sw) platforms are also explained. The simulator technology update involves many areas and to reach the goals, different specialist were required. Engineers of sw, hw, modeling, communications, maintenance and tests and faults situations as well as electronic technicians who have shared the same commitment.

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[1] http://www.iie.org.mx/site/about_us.htm

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

## II. Antecedent

According to Webopedia's Online Dictionary, a simulation is defined 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 for instance the term simulator are used herein.

Simulations is used on a great deal of contexts [6], but to simulate, it is necessary to use a simulator, which is a complex system formed by different parts like computers, peripheral devices as controllers, displays, screens, keyboards, communication network, etc., in other words, simulators need sw and hw platforms, but those platforms evolve through time, so in the next sections there is an explanation and review of how the evolution and the change of hw and sw platforms have occurred and also the expected trends of this will occur.

Since 1980, after IIE foundation, the SD has dedicate itself to developing different types of simulators for the CFE utility for training operators of the real power plants. These are full-scale simulators (FSS) operating on a control room (replica), reach based on mimics of process and virtual instrumentation, simulators with basic principles and equipment maintenance and processes simulators to perform real control equipment's testing (voltage regulators, turbine velocity controller) among others. On this paper, the FSS on a control room, its evolution of hw, operating system (OS), basic sw, and input/output (I/O) platform, based on Workstation (WS) either PC technologies, as well as its tendencies and impact of standardization are described.

TABLE I
EVOLUTION ON HARDWARE, OPERATING SYSTEM, AND SOFTWARE OF THE FULL SCALE SIMULATORS DEVELOPED BY IIE

| Full scale simulator | Technology platform | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Original | | | Updated | | | Tendency | | |
| | Computer & I/O platform | Operating system | Software | Computer & I/O platform | Operating system | Software | Computer & I/O platform | Operating system | Software |
| 300 MW Fossil Fuel Power Plant STERMOS-I CNCAOI [2] | 1984 | | | 1999 | | | 2006-2007 | | |
| | Gould 32/77 RTP 7431/30 | MPX-32 | Fortran Lib MPX32 | WS Alpha HP/Digital RTP 6700 | Digital Unix TRU64 4.0G | Fortran 97 Oracle DB DataViews C++ | PC P4 @ 3.8 GHz | Windows XP | Access DB 2005 C# |
| Nuclear Power Plant SCNLV [3] | 1990 | | | 1998 | | | | | |
| | Gould 32/67 SAC IBUS-II | MPX-32 | Fortran Lib MPX32 | WS Alpha HP/Digital Same I/O platform | Digital Unix TRU64 4.0G | Fortran 97 Oracle DB DataViews C++ | In 2005 the end user decided to evolve to a new software platform keeping all instruments and its panel board. | | |
| 350 MW Fossil Fuel Power Plant STERMOS-II CNCAOI | 1992 | | | 2002 | | | 2006 → | | |
| | Encore 32/97 MAC IBUS-II | MPX-32 Windows 3.1 DOS | Fortran Lib Doctor Halo C ANSI | WS Alpha HP/Digital RTP 2300 | Digital Unix TRU64 5.1A | Fortran 97 Oracle DB DataViews C++ | | Windows XP | |
| | | | | 2005 | | | | | |
| | | | | PC P4 @ 3.8 GHz Elimination of instrumentation & its panel Incorporation of PDP | Windows XP | Access DB Visual Studio Standard 2005 (C#) Fortran 9.0 Intel Flash MacroMedia | | | |
| Combined Cycle Power Plant STERMOS-III CNCAOI | 2000 | | | | | | 2006 → 2007 | | |
| | PC Pentium 2 @ 300 MHz Only emergency turbine stop using one NI digital input board | Windows NT | ProTRAX Fortran | | | | PC P4 @ 3.8 GHz | Windows XP | Access DB Visual Studio Standard 2005 (C#) Fortran 9.0 Intel Flash Macro Media |
| | | | | | | | This simulator was not updated, it was only replicated. | | |
| Geothermal Power Plant SGEOS[4] CESIGE [5] | 1999-2000 | | | 2005 | | | 2006-2007 → | | |
| | WS Alpha RTP 6700 | Digital Unix 4.0G | Fortran 97 Oracle DB DataViews C++ | PC P4 @ 3.8 GHz Graphical emulation of instruments control board | Windows XP | Access DB Visual Studio Standard 2005 (C#) Fortran 9.0 Intel Flash MacroMedia | High density I/O NI controllers Incorporation of PDP or LCD [6] | Windows XP | |

## III. EVOLUTION

In the original developments of the diverse simulators, most of the used tools they were rudimentary. The constant change and creation of new technologies in the main scope of the hw, OS and programming, combined to the prevention of obsolescence of each simulator, the IIE has given support to the CFE innovating the technologies originally developed to maintain to the simulators updated. Table I shows the evolution of the main areas or components that conform the simulators, initiating in its original conception and first version, going through the diverse updates that have been implanted until their tendency that is anticipated in each one of them.

[2] CNCAOI, National Center for Training and Qualification for Operators from diverse thermoelectric and combined cycle power, located on Valle de Bravo.
[3] SCNLV, Operators Training Center from the Nuclear Power Plant, located near the power plant on Veracruz.
[4] SGEOS, Geothermal Power Plant Simulator
[5] CESIGE, Geothermal Power Plant Simulator Training Center, located near the power plant on Mexicali.
[6] PDP, Plasma Display Panel; LCD, Liquid Crystal Display

The first FSS that the IIE developed, the main computer, was a "microcomputer", technologies that at their time reached calculation capacities, speed of data processing and satisfactory response times to cover the necessities of simulation which they corresponded, very near to the control rooms of the plants of electrical generation and allowed the training and qualification of operators who worked in real power plants [5].

In these simulators several common systems, as shown in Fig. 1, are identified: Instructor Console (CI): mathematical processes, commonly denominated models; data base and global memory (AMG), where diverse systems converge to interchange values of a quantity of variables, from 14,000 up to 60,000 depending of the simulator complexity; and the I/O system formed by different parts of the instrumentation panel as controllers, displays, graphical screens, hand switches, measuring indicator, lights, etc. all of them connected to a communication network.

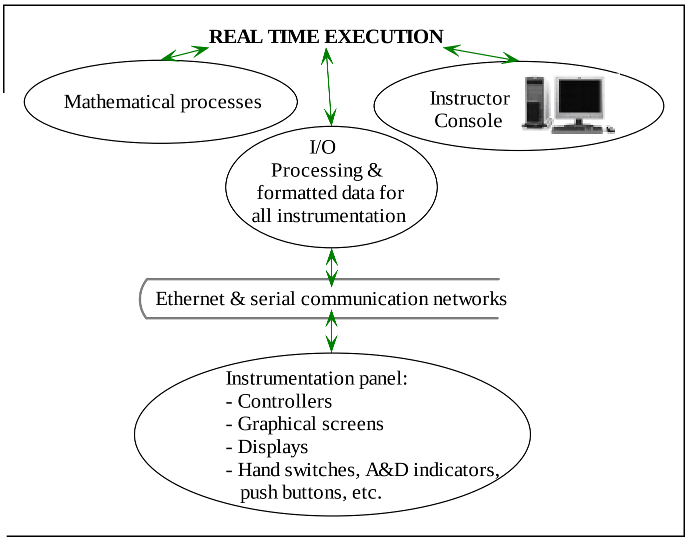


Fig. 1 Common systems on IIE simulators

On the next section, a description of the Full Scale Simulators is explained as well as relevant aspects of the original architecture, its evolution, contribution, and tendencies.

## THERMAL POWER PLANT SIMULATOR, STERMOS-I

On 1996 the IIE finished the construction and put on service a simulator for the thermoelectric power plants STERMOS-I for training operators, at the Training Center of Ixtapantongo (CNCAOI).

**Previous architecture**.- The equipment used in this simulator, as shown in Fig. 2, was formed by a set of 2 GOULD/SEL 32/77 mini computers sharing common memory with a third computer, all of them appeared in the market on 1980. This type of computers represented the best option to serve as platform of real time calculation applications. The man-machine-interface (IHM) or Instructor Console (CI) was constituted by an AYDIN equipment and VT100 video terminals. The equipment of I/O acquisition signals was RTP 7431/30 [1]. This architecture worked for more than 17 years, and for evident reasons, at the present time, it has many disadvantages and high cost for its maintenance, in addition to the difficulty that implies providing itself with spare parts.

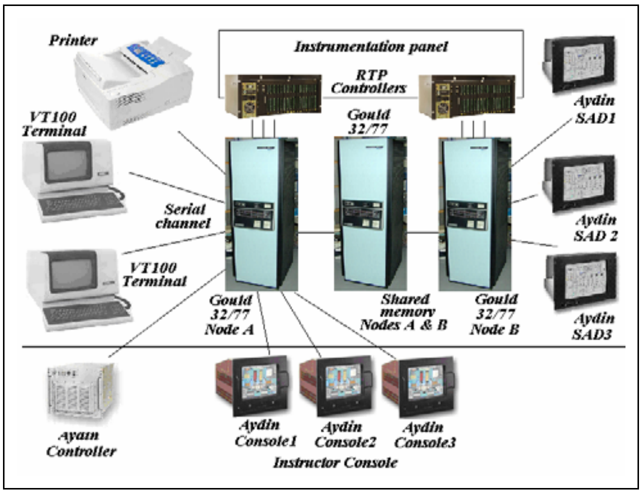


Fig. 2 STERMOS-I previous architecture

**Current architecture**.- The current architecture with recent technologies presents advantages like:

- Use of standard sw platforms: Fortran ANSI and C
- Licenses of commercial sw maintenance service and spare parts with guarantee according to the conditions given by each manufacturer.
- Compact peripheral equipment based on standards, reason why the compatibility of future components will be assured.
- The preventive maintenance to the new platform will be simple and fast resulting a saving in maintenance.

Present architecture, in Fig. 3, is constituted basically by a WS as HP-Compaq central computer at 1 GHz with simultaneous 21" monitors through a Ethernet 10/100 Mbps network, with a maintenance WS; with PC-SAD that emulate the system of acquisition of the power station; PC-NRF with the functions to produce environment plant noises and visual flames; PCs to replace instrumentation boards like the multipoint registers and the I/O controllers model RTP7431/30.

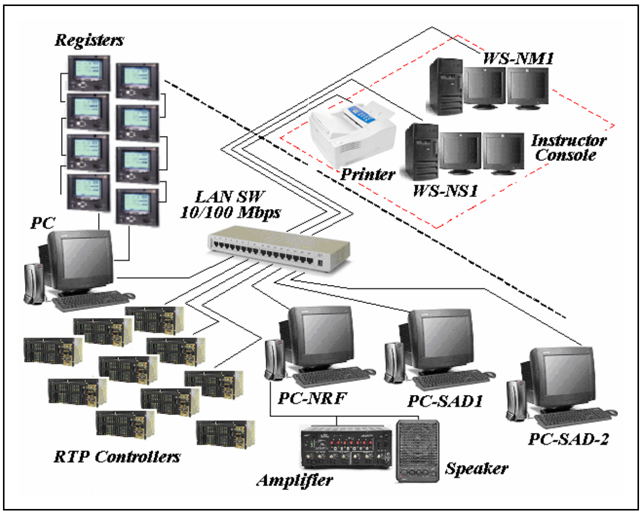


Fig. 3 STERMOS-I current architecture

## SCNLV, NUCLEAR POWER PLANT SIMULATOR

The Nuclear Power Plant Simulator (SCNLV) was finished on 1991. The SCNLV was intended to simulate two nuclear units of 800 MW each one of the Nuclear Power Plant Laguna Verde, México. See Fig. 4.

**Previous architecture**.- The previous equipment was constituted by three GOULD 32/67 minicomputers. This computer equipment presented the following situation:

- Obsolete and discontinued equipment that required high maintenance and spare parts costs.
- Saturation of the processing capacity, it is not possible to add modules like a supervisory system of the power plant (SIIP) without hitting the real time simulation.
- Sw utilities are not friendly, so maintenance of data bases is inefficient, as well as if it is desired to improve a better IHM important efforts of engineering will be required.

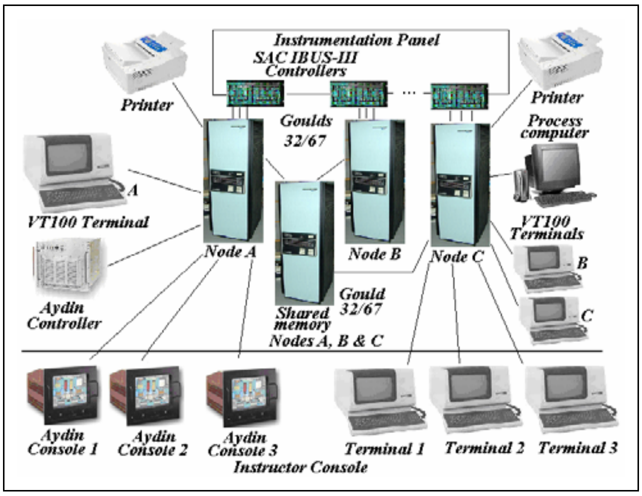


Fig. 4 SCNLV previous architecture

The original hw architecture was constituted basically by 3 GOULD 32/67 minicomputers as central equipment and connected to another GOULD as shared memory module. The IHM was constituted by an AYDIN equipment, Printronix dot matrix and VT100 video-terminals. The I/O equipment consists of 87 SAC[7] controllers, proprietary model of the IIE.

**2005 architecture**.- The current platform has the following advantages:

- Open systems based on industrial standards.
- Maintenance service guaranteed within 48 hours, with national representatives.
- Operation equipment does not demand special humidity and temperature control.
- Low energy consumption.
- Initial processing quote ten times higher.
- Compact peripheral equipment based on industrial standards.

2005 architecture is constituted basically by one HP-Compaq WS as central computer at 1 GHz with 21 dual monitors. This WS is integrated within a 10/100 Mbps Ethernet network with a WS as maintenance equipment and a supervisory SIIP of the central power units. See Fig. 5.

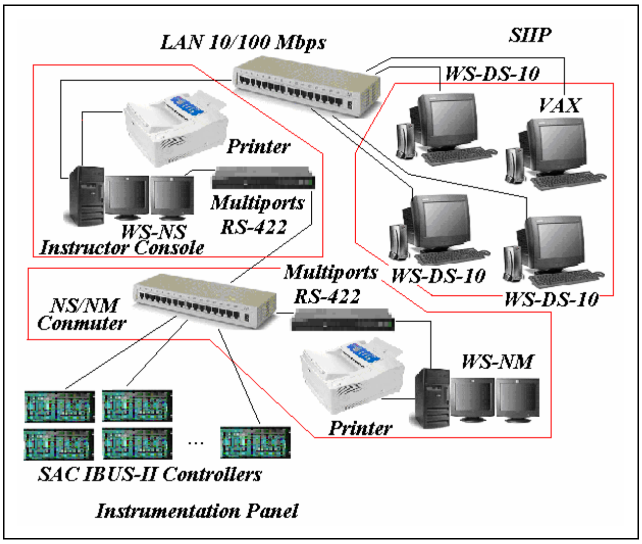


Fig. 5 SCNLV 2005 architecture

## THERMAL POWER PLANT SIMULATOR STERMOS-II

In the year of 1994, the IIE and SIMEX utility finished the construction of another simulator for the normalized thermal power plants at CNCAOI, as shown on Fig. 6.

**Previous architecture**.- The computer equipment of the STERMOS-II was formed by an 32/97 ENCORE [3] computer, of two processors and accelerator of floating point wit OS MPX-32. This type of computer the last one of dynasty, presented prematurely obsolescence. The IHM was constituted by PCs X486 communicating with the central computer through the port series and serial VT100 video-

[7] SAC, Control & Acquisition System, several generations of a family of I/O electronic boards designed and manufactured by the IIE.

terminals. The I/O equipment with the instrumentation of control boards is proprietary model MAC of the IIE.

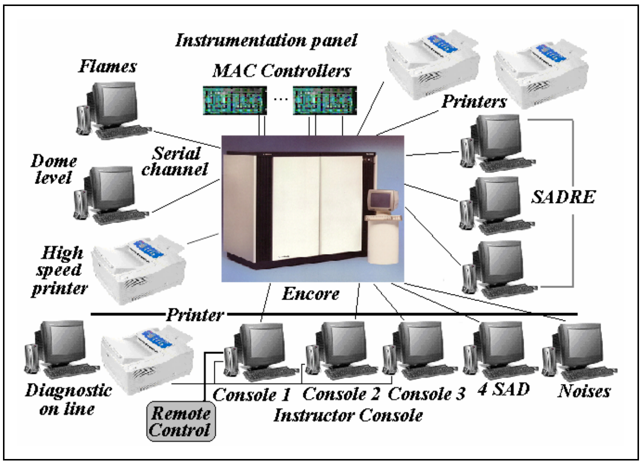


Fig. 6 STERMOS-II previous architecture

**First updated architecture**.- In the STERMOS-II one updated has occurred. As Fig. 7 shows, the computer equipment is formed by recent technologies and advantages like:

- Standard sw: Fortran, C ANSI, DataViews, and Oracle.
- Open system and current computer platform.
- HP Tru64 UNIX V5.1A and Windows 2000 OS.
- Master and simple preventive maintenance programs, resulting on saving maintenance costs.

The current architecture is formed basically by one HP-Compaq computer at 1 GHz with 21" simultaneous monitors. All together connected through 10/100 Mbps Ethernet network; one WS for maintenance, with PCs Pentium 4 that emulate Flame System and Dome Level, and 5 PCs for the SADRE, SADI, SADO, and ECC particular systems as well as PCs that display virtual instruments like synchroscope and others I/O modules. Also there are MAC controllers, which is a technology derived from SAC controllers, mentioned above.

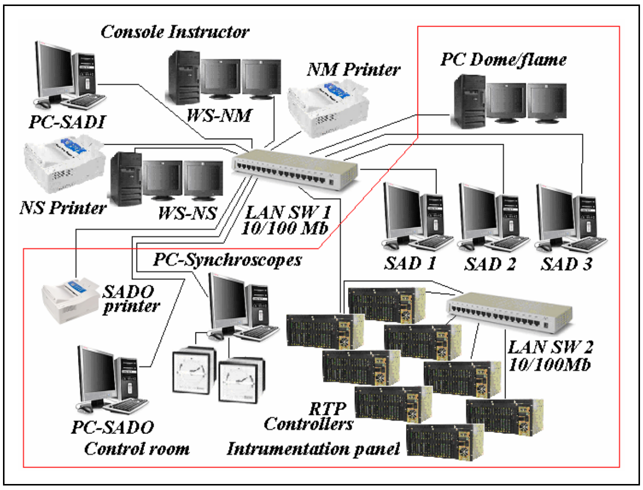


Fig. 7 STERMOS-II first updated architecture

**Current architecture**.- The STERMOS-II uses as a reference a thermoelectric unit of 311 MW, over this unit, the normalized control system was updated to one type distributed control, reason why the operators of this type required to become qualified in the Simulator with a system of similar control.

The simulator consists of a network of PC Pentium 4 at 3.8 GHz with OS Windows XP and 20" monitors as well as 50" PDP as it is in Fig. 8.

The used sw packages are of low cost in comparison with the acquired commercial packages in the simulator under WS-Unix platform. The commercial packages are: Fortran ANSI, Visual Studio C#, Access, Micromedia Professional Flash MX 2004.

The operation interface of different scenes from training is through virtual instrumentation and process diagrams in two control stations, similar to the existing ones in the Distributed Control System (SCD) of a 311 MW thermoelectric real unit.

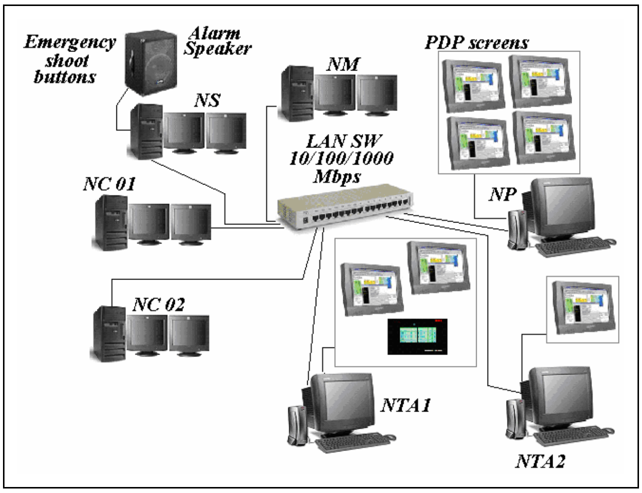


Fig. 8 STERMOS-II current architecture

## SIMULATOR OF COMBINED CYCLE POWER PLANT, STERMOS-III

Concerning to the power generation plants, combined cycle power plants (CCC) represent a different alternative from commonly used plants in Mexico.

This FSS for training CCC operators has a design reference a unit of 160 MW. The development of the simulator is based on the sw package specialized for the development of simulators of fossil plants denominated ProTRAX version 6.1.

**Current architecture**.- As Fig. 9 shows, the simulator [2] is constituted by 7 PC Pentium II at 300 MHz with Windows NT incorporated, and connected to a fast Ethernet network. These equipments will provide the basement for the operation of the simulator on which one of the nodes will execute the part of models using a commercial package of simulation. Whereas the rest of the nodes will complement to this one to make functions of the system of distributed control, control of pollution emissions, noises of the power plant implemented on the simulator and control of the turbine. This allow all together with the operations of consoles of the control room, to carry out the simulation to the operation of the generating unit.

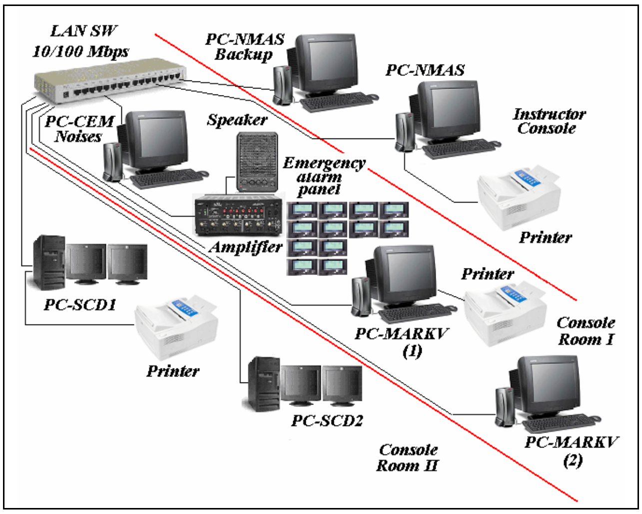


Fig. 9 STERMOS-III original architecture

To update CCC simulator, there is a proposed architecture as shown in Fig. 10, where all the computers or nodes are connected through a LAN concentrator and all process diagrams are displayed on PDP, and there is no physical instrumentation panel.

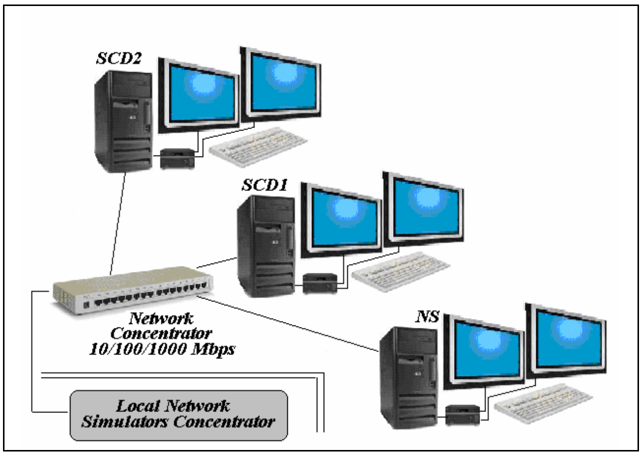


Fig. 10 STERMOS-III proposed architecture

## GEOTHERMAL POWER PLANT SIMULATOR, GEOS

The Geothermal Power Plant Simulator (SGEOS) was developed as Unix version based on WS computer platform.

**Previous hardware**.- The previous hw architecture [4] of the SGEOS, shown in Fig. 11, was composed by WS; I/O boards controller; digital and analog instrumentation; a synchroscope; a Power Measurement (PM) display; the Ethernet network between CI with two screens NC1 and NC2, a maintenance node with two screens (ND1 and ND2), a Real Time Node where the synchronous tasks were executed and the I/O processor that communicated the WS with the hard panel using a TCP/IP protocol; and the RTP controllers [1], one serial RS-232 channel, and analog displays among others.

The Unix version handled one analogical entry signals, 316 analogical exit signals, 535 digital entry signals and 824 digital exit signals.

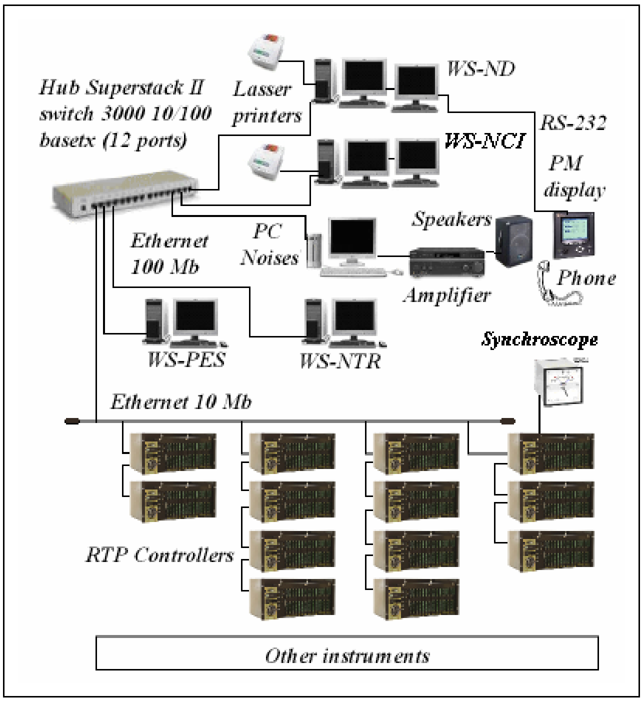


Fig. 11 SGEOS previous architecture

**Current hardware**.- Fig. 12 shows the current hw platform. This new one has the following modifications:

- WS of Simulation Node and Maintenance Node were substituted by two PCs (NS and NM) and incorporated with its own IP to the Ethernet network. In these processors the tasks of the former real time node and the I/O node are executed.
- Two less RTP controllers, because sixteen electromechanical registers were substituted by screens, and driven by two additional PCs; each one has two additional graphic boards with capacity to lead up to eight screens. Communication RTP format protocol remains the same.
- A Vacuum column was added by a 780 LED level column and driven by a new PC using ASCII 6 bytes communication protocol at 19,200 bauds via RS-232.
- Bently analog indicators were substituted by an 8 module LED level column and driven by a PC using six ASCII bytes communication protocol at 38,400 bauds via RS-232.
- PM driven physically through an USB/RS-232 signal converter.

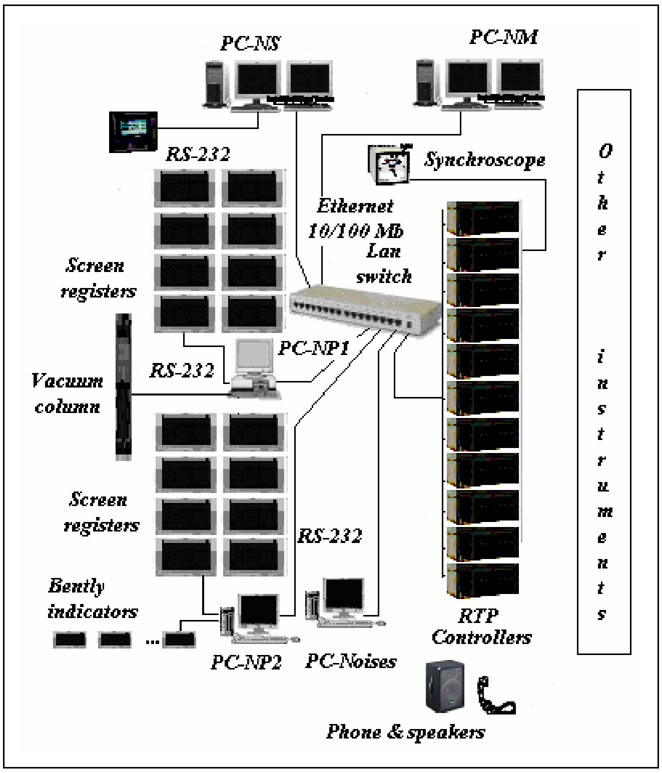


Fig. 12 SGEOS current architecture

After updating the SGEOS simulator, the PC version was formed by the number of signals processed by the I/O protocol such as one analogical entry signals, 189 analogical exit signals, 341 digital entry signals and 815 digital exit signals [7].

## IV. Tendencies

From the description done in previous sections, it is observed that the tendencies in the developments of FSS realized by the IIE go towards on:

- A decrease or complete reduction of physical instrumentation for virtual instrumentation emulated on graphic screens, presenting to the operator the same mask and functionality as the real instruments.
- This leads to progress in the application and development of newest and most modern technology of FSS.
- The FSS tends to continue the innovations that are realized in the control rooms, with the purpose of getting better understanding to the operators under training and to enrich their cultural heritage of preparation before possible risks and faults during the daily operation.
- FSS can be performed faster, attributable this to the advances in hw that permit rapid running of scenarios.

Table II and Fig. 13 summarize the updated, evolution and tendencies on the full scale simulator, developed by the IIE.

TABLE II
Total of Analog and Digital I/O Signals of the Full Scale Simulators Developed by IIE and Their Tendencies

| **Full scale simulator** | **Before** | | | | | **After updated** | | | | | **U=Updated/T=Tendencies** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Analog | | Digital | | | Analog | | Digital | | | |
| | Output | Input | Output | | Input | Output | Input | Output | | Input | |
| | | | Normal | Alarm | | | | Normal | Alarm | | |
| STermos-I | 257 | 20 | 861 | 408 | 690 | 257 | 20 | 861 | 408 | 537 | (U) To replace electromechanical registers by LCD flat monitors<br>(T) Elimination of total instrumentation panel<br>To emulate all instrumentation through four 50" PDP |
| SCNLV | 1069 | 41 | 5198 | 1466 | 4303 | 1069 | 41 | 5198 | 1466 | 4303 | (U) In 2005 the end user decided to expire its life utility |
| STermos-II | 428 | 10 | 2224 | 631 | 1248 | --- | 10 | 224 | 631 | 1248 | (U) 428 AO signals were replaced by LCD monitors<br>Two Synchroscopes were substituted and emulated by two LCD flat monitors<br>Elimination of total instrumentation panel<br>All instrumentation is emulated on four 50" PDP |
| STermos-III | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | (U) All instrumentation panel emulated on PC monitors |
| SGEOS | 316 | 1 | 484 | 340 | 535 | 189 | 1 | 465 | 350 | 341 | (T) To replace digital and analogical signals by flat LCD monitors and I/O controllers by a modern equipment |

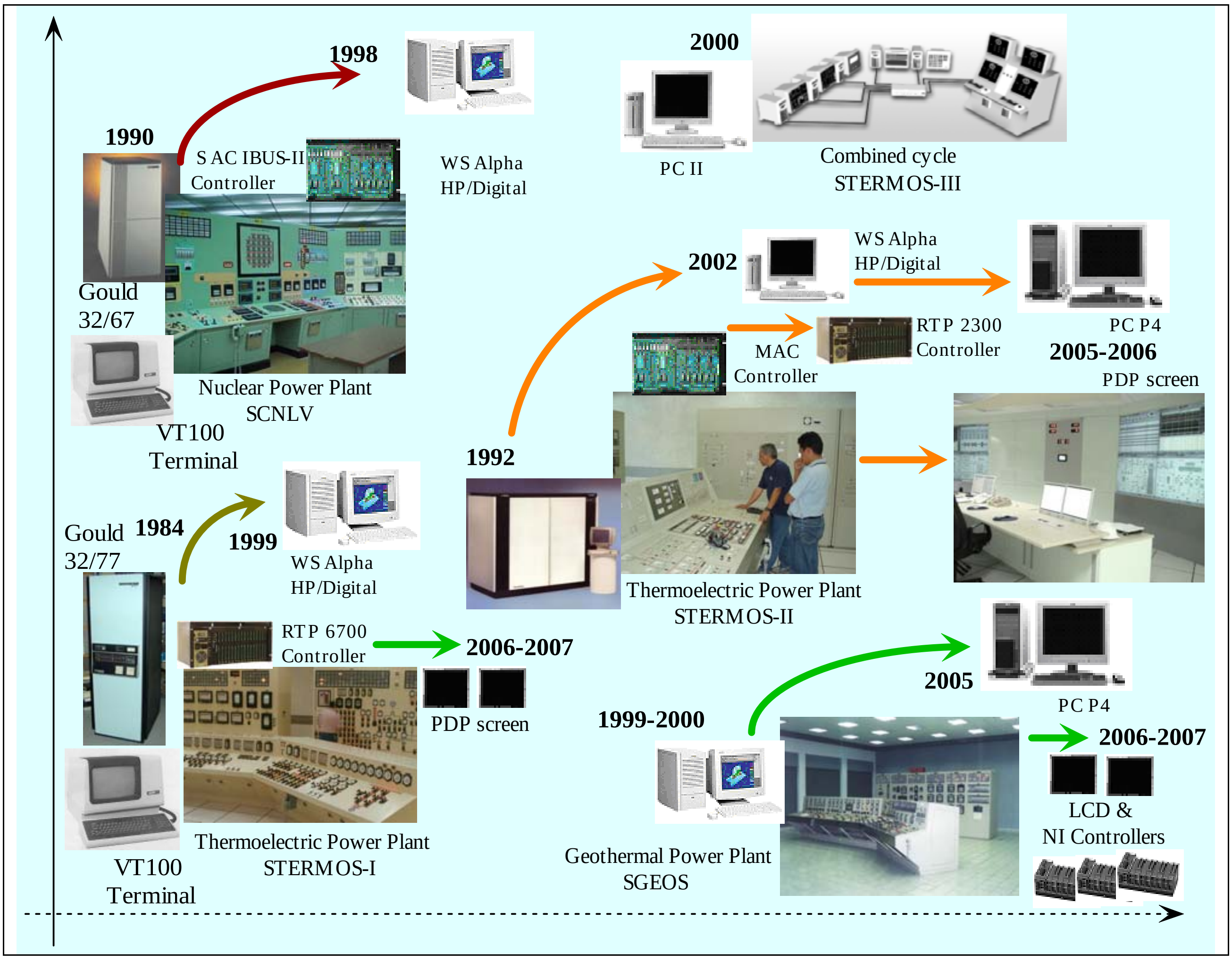


Fig. 13 Groups of simulators with its original basic computer & I/O platform, their respective updates and tendencies

## V. Impact

The impact that these developments present, can resumed in the following:

1. Update of the operators in identical or very similar FSS to the control rooms.
2. Major practical specialization of the power plant operators.
3. Rapid evolution of the use of top technologies.
4. Operators that use to operate power plant on a control room by means of the use of classic input/output instrumentation must rapidly migrate to virtual instrumentation and to graphic screens.
5. Robustness to the simulation behaviors.
6. Standardization of the training ways.
7. Prepare operators for the future that will bring change.
8. Operators under training can answer all of the what-if questions concerning to a several faults that could be so difficult in a real way or even impossible to reproduce.

## VI. Conclusion

This article presented the previous and the current of some of the full scale simulators developed by the IIE and contributes to the dissemination literature on this topic and increases the knowledge of the modernization of this range of simulators.

The benefits of the organization can be concluded as well as the tendency to which they are directed with the future updates as following:

- Better acceptance of the operator to new technologies.
- A suitable selection of personnel, because in a simulator the abilities of the operators can be tested.
- To reach the state-of-the-art on full scale simulators, because the advance in graphical systems, nowadays the qualification of operators tends to use these tools, doing to the training something more express, interactive and friendly.
- Operation faults by human errors are reduced, so reliable operation of the power plants is guaranteed.

- With the modernization of power plants, equipment and processes, it is necessary to maintain the operators in a state of information permanently updated to guarantee the optimal operation of the equipment.

This article enriches the knowledge of the state-of-the-art of the full scales simulators and contributes to the diffusion of the modernization the simulators developed by the Simulation Department of the IIE.

Tendencies on the I/O architecture of these full scale simulators described above are the followings:

- Development on PC hw platform.
- Reduction of hw instrumentation.
- Substitution of more current instrumentation by PDP or LCD technology for displaying virtual instrumentation, like the alarm panel, trend registers, synchroscope, among others.
- Lower costs of hw implementation.
- Smaller training room area.
- Reduction time of project development.

## 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 (CNLV, CESIGE and CNCAOI training centers).

About the SD personnel's labor, it is necessary to mention researchers for their contribution during design steps, implementation and final tests concerning to I/O of different simulators: L. Carrillo was involved in the updated of the I/O platform as well as implementation of the graphical instrumentation in STERMOS-I and SGEOS; R. Martínez during replication of the STERMOS-III and incorporation of sw for the screen registers group and vacuum column in SGEOS; J. Montoya for his experience and contribution in the replication of STERMOS-III; and L.A. Jiménez involved on simulation sw environment design and implementation of I/O boards for updating STERMOS-II.

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