DEVELOPMENT OF A CANDU FULL SCOPE SIMULATOR FOR THE EMBALSE NUCLEAR POWER STATION

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Abstract

L-3 MAPPS has developed CANDU 6 full scope operator training simulators for nearly four (4) decades (since 1973). The last full scope CANDU simulator that was developed was for Qinshan Phase II plant in Zhejiang, China and the simulator was put into service in the first quarter of 2003. Up to this point, L-3 MAPPS simulators for CANDU plants had largely capitalized on legacy technologies developed in the 1970's and 1980's. In the meantime, significant technology advances were made on simulator programs for Light Water Reactors and gas-cooled reactors and through upgrades to select CANDU plant simulators. In the third quarter of 2010, L-3 MAPPS was awarded the contract for a full scope simulator for the Embalse nuclear power station in Córdoba Province, Argentina. Through the development of this project, L-3 MAPPS has devised a full scope operator training simulator base on state-of-the-art technologies (both hardware and software) and simulation techniques.

1. Introduction

L-3 MAPPS has been developing CANDU 6 full scope operator training simulators since 1973. In the last four (4) decades L-3 MAPPS was contracted for eleven (11) separate full scope simulators as well as several upgrade projects, as seen in Table 1. The last full scope CANDU simulator that was developed was for the Qinshan Phase III plant in Zhejiang, China and the simulator was put into service in the first quarter of 2003. Up to this point, L-3 MAPPS simulators for CANDU plants had largely capitalized on legacy technologies developed in the 1970's and 1980's. In the meantime, significant technology advances were made on simulator programs for Light Water Reactors and gas-cooled reactors and through upgrades to select CANDU plant simulators. In the third quarter of 2010, Nucleoeléctrica Argentina S.A. (NA-SA) awarded L-3 MAPPS a contract to develop, install and commission a full scope simulator for the Embalse nuclear power station in Córdoba Province, Argentina.

The Embalse nuclear power station is one of two operational nuclear power plants in Argentina. It is located on the southern shore of a reservoir on the Rio Tercero, near the city of Embalse in Córdoba Province, 110 kilometers southwest of Córdoba City. The single unit at Embalse is a CANDU pressurized heavy water reactor with a net output of 600 MWe, which went into commercial operation on 20 January 1984. Embalse also produces the cobalt-60 radioisotope, which is used for cancer therapy and industrial applications. With the ongoing plant refurbishment, the plant's life is expected to be extended for another 25 years.

The Embalse full scope simulator uses L-3 MAPPS' cutting-edge graphical simulation PC/Windows-based tools for the plant models and instructor station. The majority of the simulator's models are developed, validated and maintained in L-3's Orchid® simulation environment. The plant computer systems, known as Digital Control Computers (DCCs), are represented with a fully

emulated dual DCC that is integrated in the full scope simulator. The simulator is also equipped with full replica control room panels. A simplified block diagram of the Embalse simulator hardware architecture is shown in Figure 1.

In this paper, L-3 MAPPS outlines some of the novel Orchid® technologies applied to building the Embalse full scope simulator.

Table 1 L-3 MAPPS experience with CANDU simulation

Plant	Country	Owner/Operator	Project Scope	Project Start
Point Lepreau	Canada	NB Power	I/O Replacement	2011
Embalse	Argentina	Nucleoeléctrica Argentina S.A.	Full Scope Simulator	2010
Gentilly-2	Canada	Hydro-Québec	Simulator Rehost, Instructor Station, Models Upgrade, Stimulated & Emulated Plant Control Computers	2009
Cernavoda 1,2	Romania	Nuclearelectrica	Desktop Simulator	2009
Wolsong 2	Korea	Korea Hydro & Nuclear Power Co.	Simulator Replacement	2007
Cernavoda 1,2	Romania	Nuclearelectrica	Major Upgrade	2003
Gentilly-2	Canada	Hydro-Québec	Virtual Panels	2002
Cernavoda 1,2	Romania	Nuclearelectrica	Instructor Station, Desktop Simulator	2000
Gentilly-2	Canada	Hydro-Québec	Simulator Rehost	1999
Qinshan Ph. III	China	Third Qinshan Nuclear Power Co.	Full Scope Simulator	1998
Pickering A	Canada	Ontario Power Generation	I/O Replacement	1995
Wolsong 2,3,4	Korea	Korea Hydro & Nuclear Power Co.	Full Scope Simulator	1994
Pickering A	Canada	Ontario Power Generation	Major Simulator Upgrade	1992
Cernavoda 1,2	Romania	Societatea Nationala Nuclearelectrica	Full Scope Simulator	1992
Point Lepreau	Canada	NB Power	Full Scope Simulator	1988
Gentilly-2	Canada	Hydro-Québec	Full Scope Simulator	1985
Darlington	Canada	Ontario Power Generation	Full Scope Simulator	1983

Plant	Country	Owner/Operator	Project Scope	Project Start
Bruce B	Canada	Bruce Power	Full Scope Simulator	1982
Pickering B	Canada	Ontario Power Generation	Full Scope Simulator	1980
Bruce A	Canada	Bruce Power	Full Scope Simulator	1979
Pickering A	Canada	Ontario Power Generation	Full Scope Simulator	1973

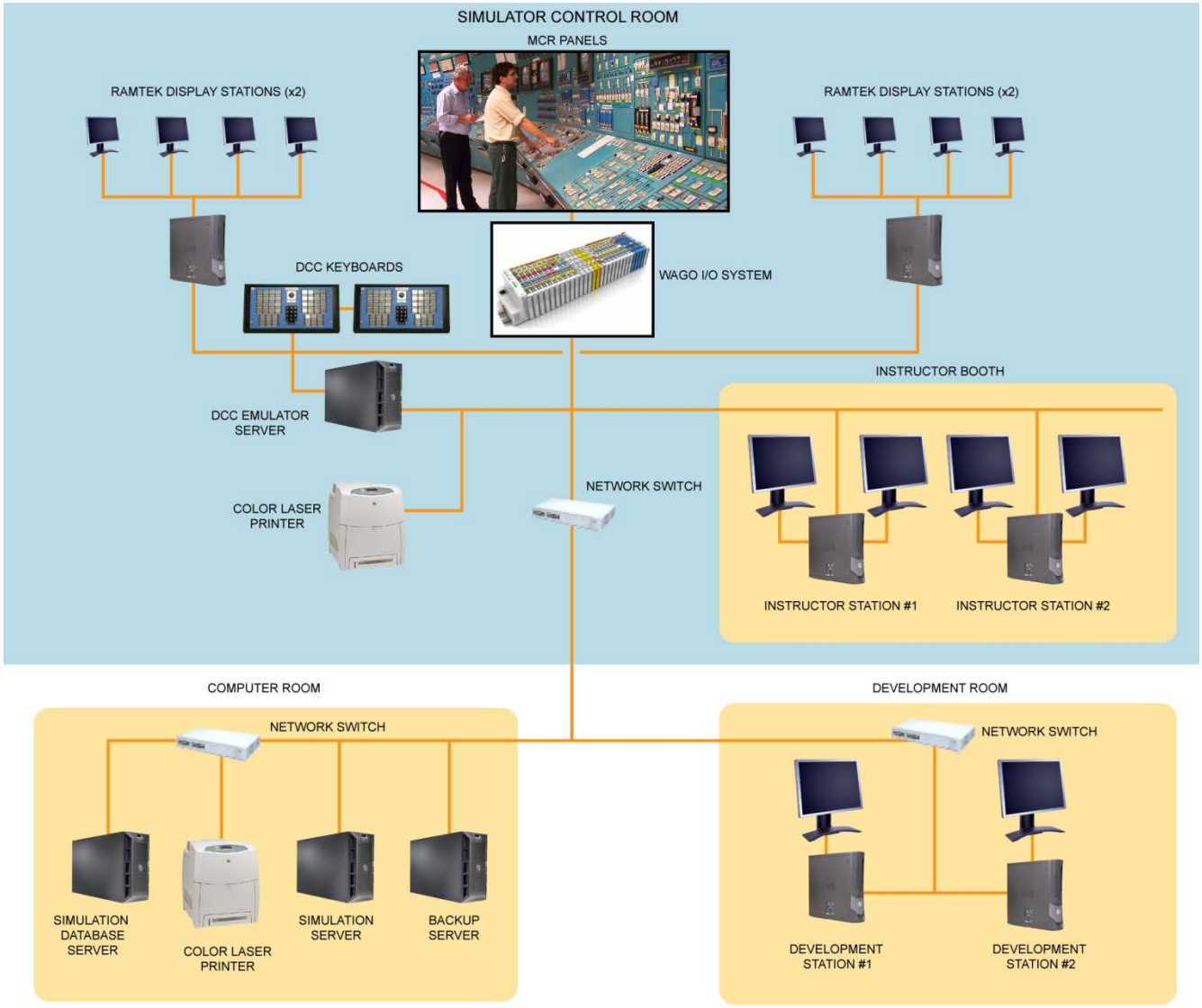

Figure 1: Simplified block diagram of Embalse simulator hardware architecture

2. Orchid® suite of simulation tools

The Orchid® suite (Figure 2) developed by L-3 MAPPS is the result of almost forty (40) years of nuclear power plant simulation experience. The Orchid® tools have been designed to be highly integrated with one another to create an effective and efficient working environment. Each tool follows a standardized approach, providing the same guidelines for menu structure, icons, documentation and even training material. A focus on using common icons, layouts, themes, and menus has greatly helped reduce the user's (both L-3 MAPPS developers and utility simulator personnel) learning curve when adopting the Orchid® products.

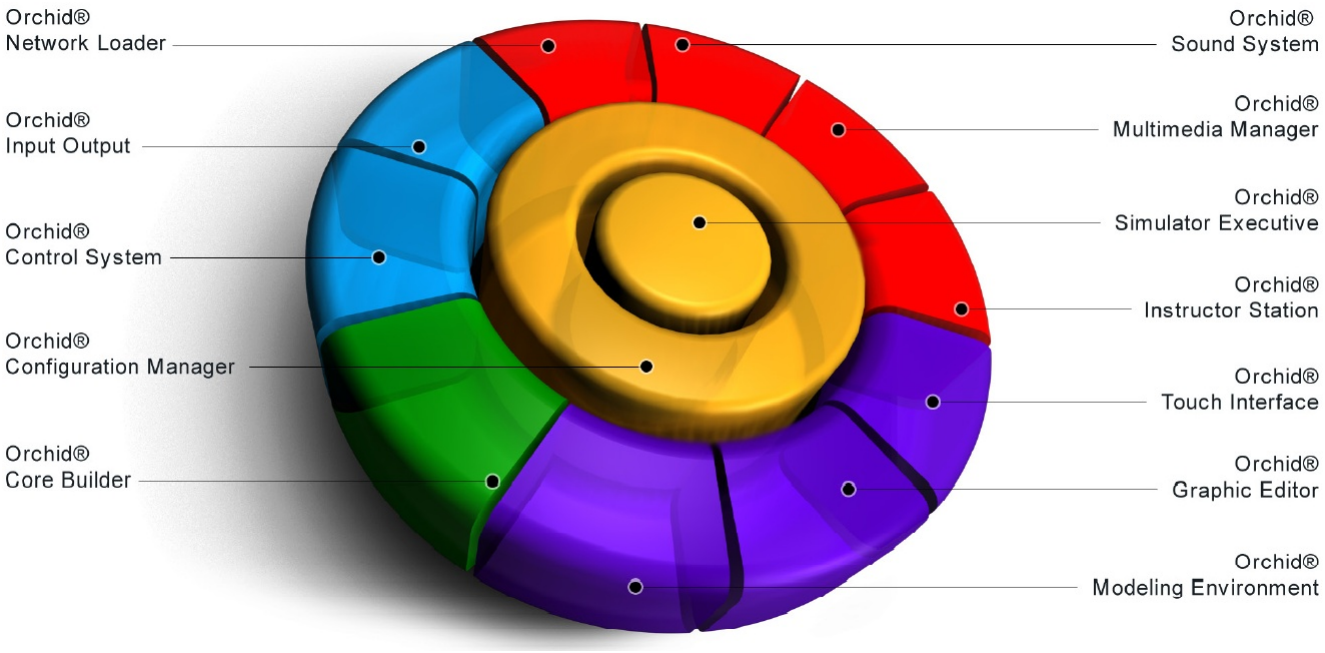

Figure 2: Orchid® suite's highly integrated tools

With all tools having a graphical user interface and high level of customizability, the Orchid® suite is the ultimate toolbox for all simulator development, operation and maintenance needs. Table 2 summarizes the wide range of tool set Orchid® provides.

Table 2 Orchid® tools description

Orchid® Tool Name	Tool Description
Orchid® Modeling Environment	Advanced real-time graphical component-based Simulation environment for model development, integration and testing
Orchid® Core Builder	Advanced cycle-specific reactor kinetics model (supporting both Nodal Expansion Method (NEM) and Mesh Centered Finite Difference (MCFD) model)
Orchid® Graphic Editor	Development environment for graphical control panel and schematic reproductions for simulator trainee action and instructor input

Orchid® Tool Name	Tool Description
Orchid® Control System	Simulator-ready Digital Control System (DCS) Human-Machine Interface (HMI) simulation
Orchid® Instructor Station	State-of-the-art modular instructor facility for controlling simulator training environment
Orchid® Touch Interface	HD touch screen technology for reproducing full simulator control room operations in the classroom
Orchid® Multimedia Manager	Flexible audio-video recording and playback application for training session reviews
Orchid® Configuration Manager	Full integrated graphical simulator configuration management utility
Orchid® Simulator Executive	Graphical real-time simulator task scheduler
Orchid® Input Output	Simulator I/O communication and diagnostics
Orchid® Network Loader	Multi-platform distributed simulation component loader
Orchid® Sound System	Simulator control room sound and noise utility

3. Simulator software

3.1 Plant system modeling

For the Embalse full scope simulator, all of the plant systems are simulated, including the reactor, nuclear steam supply systems, balance of plant systems, electrical systems and I&C systems. The majority of the systems are developed using Orchid® Modeling Environment (Orchid® ME), resulting in high-fidelity plant models. Orchid® ME is used for the entire simulator life cycle, from model design through to testing, documentation and long-term maintenance. With this tool, modelers (L-3 MAPPS, its partners and/or utility simulator personnel) create simulation models by dragging and dropping graphical objects representing plant components from libraries onto a schematic, by entering object calibration data, and by making the appropriate connections between objects. Calibration tools are also available to facilitate the calculations of specific constants required to calibrate an object instance. The schematic layout and component symbols are similar in appearance to the actual plant drawings for the system being modeled (Figure 3). Orchid® ME is used to model:

1. Homogenous, equilibrium thermal-hydraulics
2. Non-homogenous, non-equilibrium thermal hydraulics
3. Electrical distribution and generation
4. Electrical switchyard and power grid
5. Relay control logic
6. Analog and binary control logic
7. DCS control, if applicable
8. Nuclear containment and ventilation

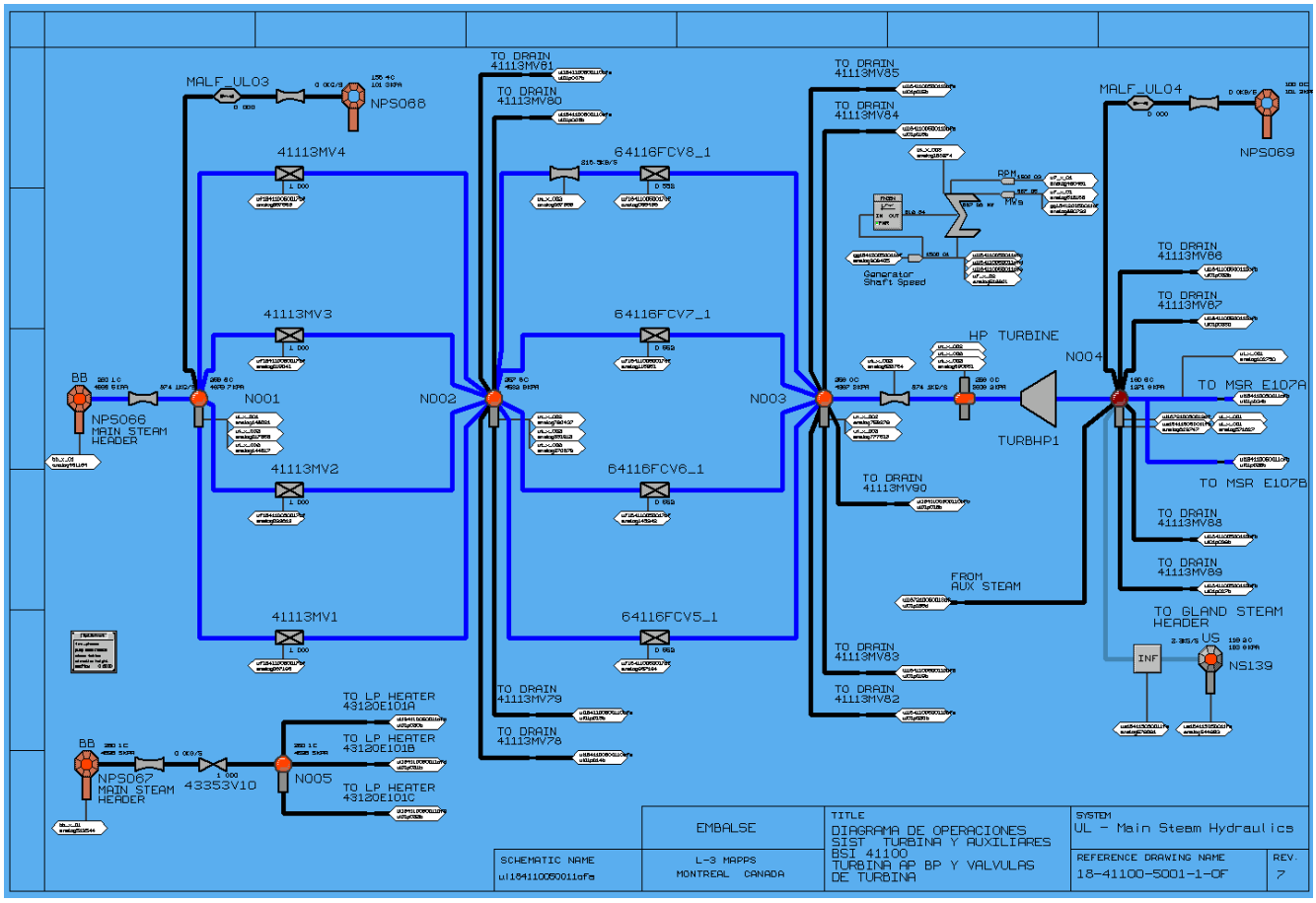

Figure 3: Orchid® Modeling Environment system schematic

The reactor kinetics model is the only model that is developed, tested and maintained outside of Orchid® Modeling Environment. The core neutronics model is founded on the fundamental equations of time-dependent neutron diffusion theory. Diffusion equations are solved at each time step using reactor design code techniques. The models developed with Orchid® Core Builder (Orchid® CB) are true two-group, three-dimensional, multi-nodal, fully dynamic models computing in real-time the flux for each node at each time step. Orchid® CB provides 2D and 3D graphics to fully validate and document the input fuel data and the output model, together with user-defined test reports (Figure 4).

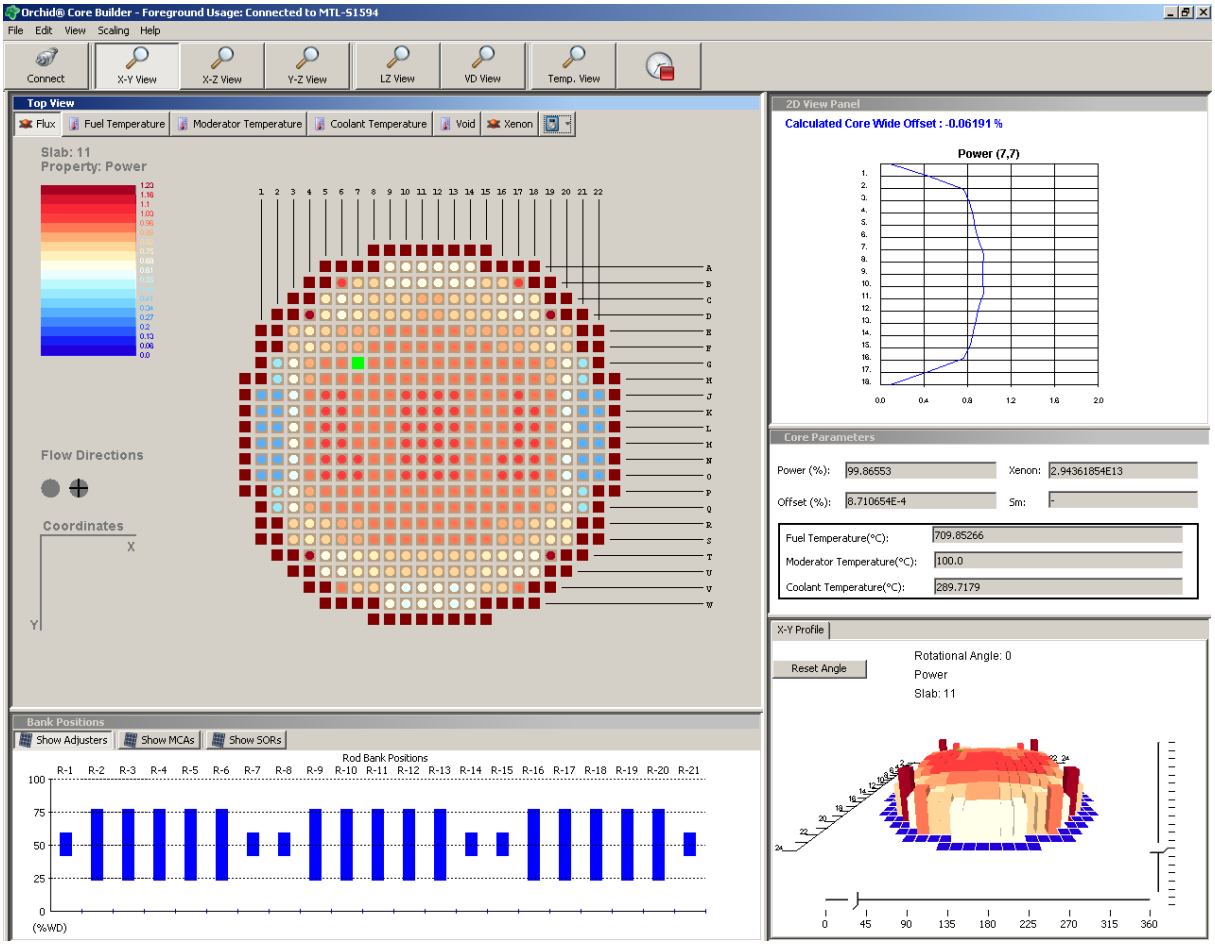

Figure 4: Orchid® Core Builder runtime visualization

The simulation models are validated against plant data when available and/or other plant information such as safety analysis reports. Figure 5 provides an example of a simulator transient test showing simulator results against plant data. An extensive set of tests, consisting of normal and abnormal plant operations as well as major accidents, is performed by L-3 MAPPS and its customers. As a minimum, simulator performance is tested in accordance with the ANSI/ANS-3.5 standard ("Nuclear Power Plant Simulators for Use in Operator Training and Examination").

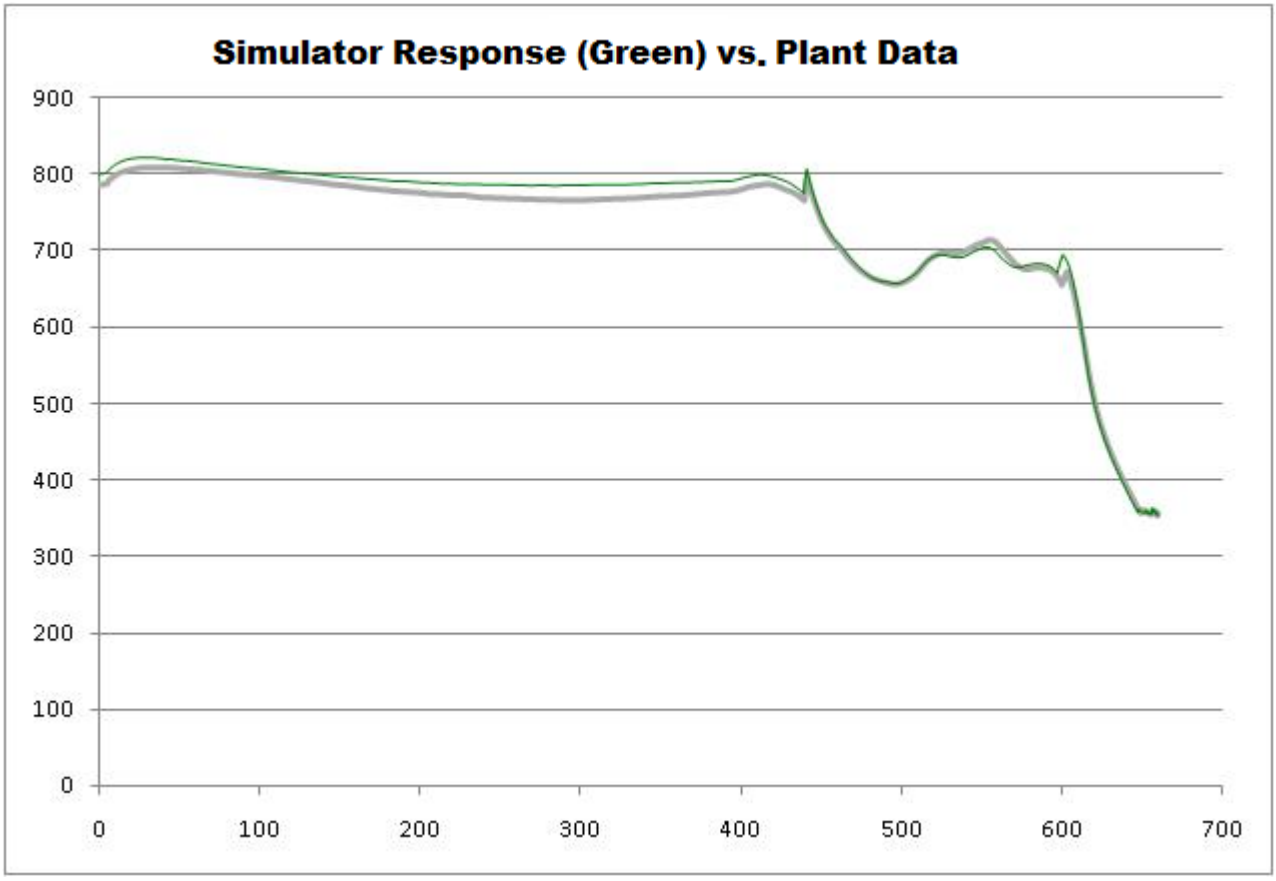

Figure 5: Simulator validation against plant data

3.2 Virtual panel displays

Using a true world coordinate system and an advanced tiling and layering scheme, Embalse's control panels are reproduced using Orchid® Graphic Editor, creating dynamic virtual panel displays used to provide a useful interactive instructor and/or student simulator interface. The tool produces vector-graphics displays that can be magnified without loss of resolution.

Designed specifically for application in training simulators, the virtual panel displays can show additional information, visible only to the simulator instructor to provide better feedback and control, while the same information is suppressed from the student or operator to prevent negative training from occurring.

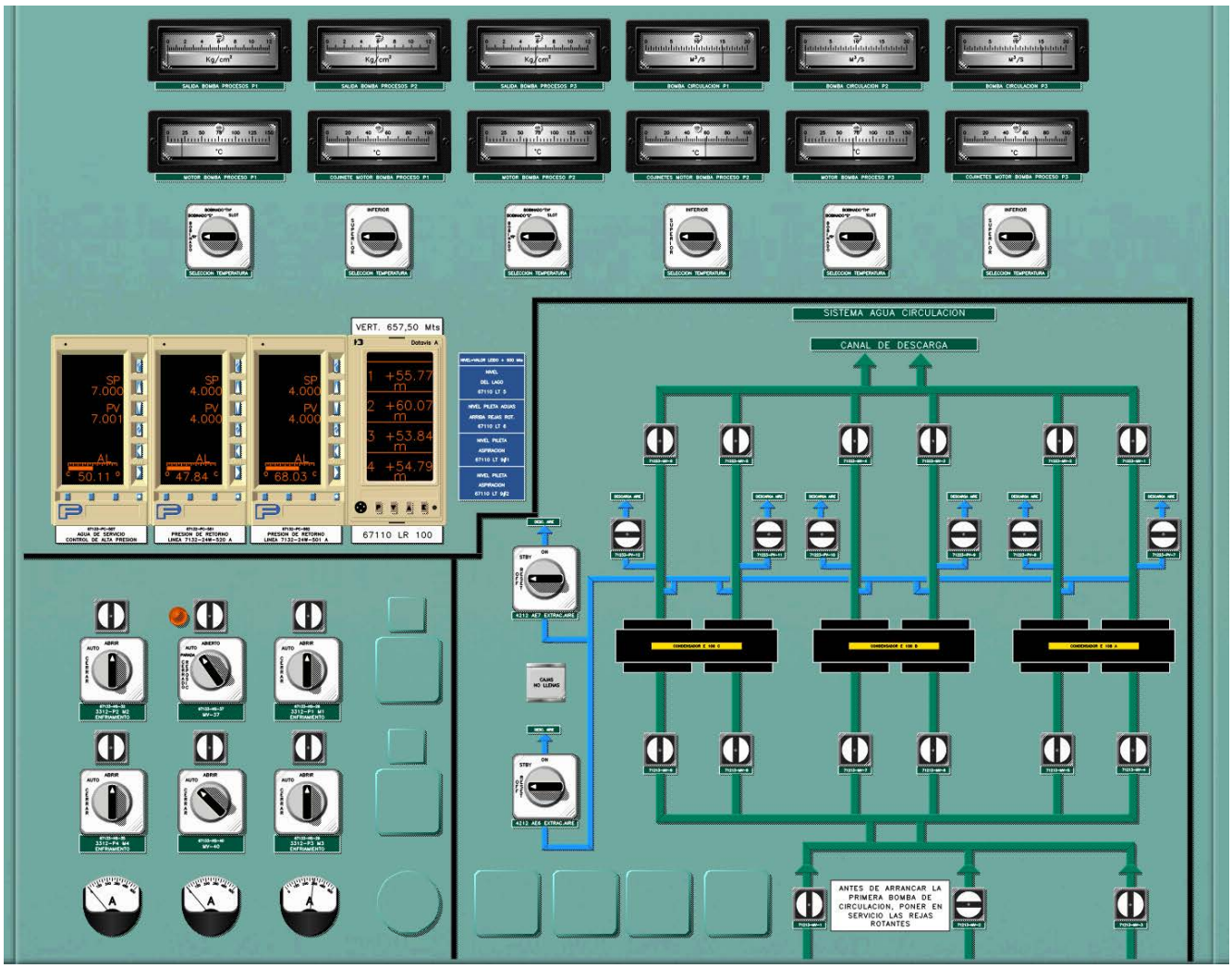

Figure 6: Embalse virtual panel displays

3.3 Digital Control Computers

In 2009, L-3 MAPPS was awarded a contract from Hydro-Québec to significantly upgrade its Gentilly-2 simulator. The project included the replacement of the actual stimulated DCCs with a fully emulated equivalent, integrated in the full scope simulator. Deploying a dual DCC emulation was a first-of-a-kind effort for L-3 MAPPS in CANDU plant simulation. The Embalse simulator takes advantage of that experience and is also equipped with a complete emulation of a dual DCC. The advantages of the DCC emulation are summarized as follows [1]:

- Low cost alternative to real DCC computers
- Easy and cost effective maintenance
- DCC emulation that can be operated with and without the physical keyboard as it also includes its own emulated keyboard
- The possibility to connect the backup simulator to a second DCC emulator to run in parallel and independently from the Full Scope Simulator to be used, among other things, for engineering purposes.

4. Simulator hardware

With emerging obsolescence issues related to legacy input/output (I/O) hardware solutions, L-3 MAPPS performed a one (1) year study to investigate new I/O hardware solutions. The study focused on system reliability, availability, flexibility and price. Additionally, L-3 MAPPS was seeking to incorporate a solution that did not require customization (to make it easy for customers to secure replacement parts easily). The study resulted in two I/O solutions that L-3 MAPPS has worked with depending on whether a centralized or distributed I/O system solution was adopted [2]. For the Embalse full scope simulator, L-3 MAPPS selected compact I/O modules mounted on DIN rails, that are distributed directly in the rear of the simulator control room panels and consoles for direct wiring to the instruments (Figure 7), eliminating the need for traditional I/O cabinets and/or I/O chassis. This solution provides ample service areas in the rear of the simulator control room panels and makes for easy maintenance.

Figure 7: Embalse distributed I/O hardware solution

To communicate and monitor the data from the simulation server to the control room hard panels, L-3 MAPPS uses Orchid® Input Output. The tool provides simulator maintenance and instructor personnel with full graphical control, monitoring, debugging and reporting capabilities (Figure 8). With the graphical user interface, the user can obtain information on the I/O modules and drill down to the individual I/O point level to view or set individual point values.

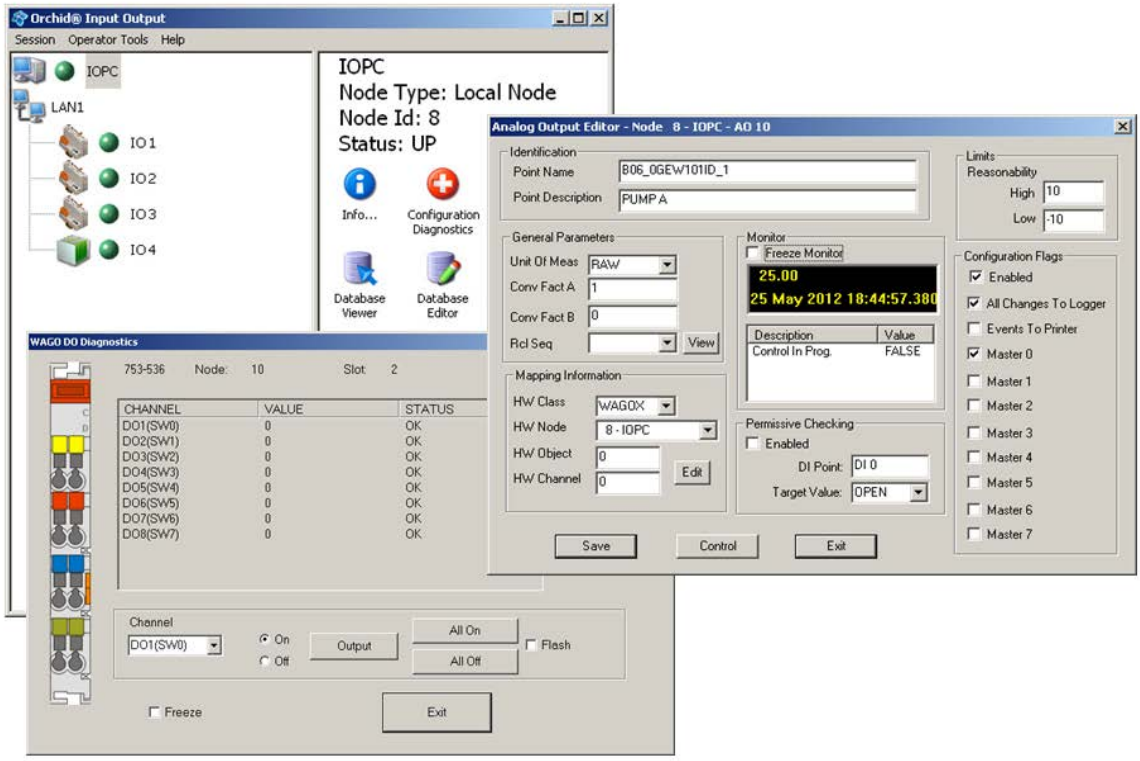

Figure 8: Sample maintenance facility within Orchid® IO

5. Conclusion

Since 1973, L-3 MAPPS has developed and fielded numerous full scope simulators, including numerous full scope simulators for CANDU plants.

Most recently, through the Embalse full scope simulator program, L-3 MAPPS has had the opportunity to extensively apply its Orchid® technology making the Embalse simulator the most state-of-the-art CANDU simulator in the world.

With the combination of Orchid® and the thorough validation that is being conducted on this program, L-3 MAPPS will be well aligned to modernize the legacy CANDU plant simulators and to deploy the same advanced solution to CANDU new build programs.

6. References

[1] C. Vincent, G. Jaar, “Modernization of the Wolsong 2, 3, 4 Simulator”, 2009 International Conference on Simulation for Power Plants, 9 February 2009.

[2] F. Mathieu, “The Simulator Input/Output System: 2011 and Beyond”, 2011 International Conference on Simulation for Power Plants, 14 February 2011.