EARLY IMPLEMENTATION OF DIGITAL UPGRADES ON SIMULATORS

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ABSTRACT

An important aspect of successful Nuclear Power Plant (NPP) digital control system upgrade projects is to upgrade the Operator Training Simulator (OTS) or a related Engineering Simulator (ES), prior to installation of the Distributed Control System (DCS) on the plant allowing for early testing of the digital controls/HMI and for early training of the plant operators while maintaining OTS configuration management (i.e. OTS in sync with the plant's current design).

Experience has shown that early implementation of digital upgrades on the OTS and/or an ES can reduce plant startup duration (related to digital systems commissioning) and ensure operators are proficient with the new digital systems to ensure safe and reliable plant operation. Including simulators in the design process offers many benefits including early identification of design deficiencies, testing deficiency fixes, developing and validating plant procedures and supporting human factors engineering, to name a few. Implementing digital upgrades on the OTS is also a regulatory requirement driven by the ANSI/ANS-3.5-2009 standard (Nuclear Power Plant Simulators for Use in Operator Training and Examination) if the new DCS affects actions to be taken by the plant operator in the main control room.

This paper presents the benefits of implementing digital upgrades on the OTS and/or ES prior to plant implementation. The various simulator implementation strategies (stimulation, emulation, simulation or a hybrid solution) and selection factors are discussed. The paper also covers four (4) case studies demonstrating how digital upgrades can be implemented on simulators. The first case study covers the implementation of a Siemens offgas Programmable Logic Controller (PLC) system on the Enrico Fermi OTS (Michigan). The second case study covers the implementation of a GE main generator excitation system on the Cernavodă OTS (Romania). The third case study covers the implementation of a Siemens main feedwater control system on the Callaway OTS and ES (Missouri). The final case study covers the implementation of the non-safety related and safety related DCS on the Nuclear New Build (NNB) Hongyanhe Phase I dual-purpose OTS/ES (China).

Key Words: simulation, stimulation, emulation, training simulator, engineering simulator.

1 INTRODUCTION

In the USA, the U.S. Nuclear Regulatory Commission (NRC) requires that NPP Senior Reactor Operators (SROs) and Reactor Operators (ROs) be trained and examined on a plant-referenced simulator [1]. The plant-referenced simulator "must demonstrate expected plant response to operator input and to normal, transient, and accident conditions to which the simulator has been designed to respond" [2]. As stated in the NRC's Regulatory Guide 1.149 [3], the Office of Nuclear Reactor Regulation (NRR) accepts and endorses the ANSI/ANS-3.5-2009 [4] with clarifications. The ANSI/ANS-3.5-2009 standard establishes the functional requirements for full scope NPP control room simulators for use in operator training and examination. The standard also establishes the following requirement related to plant modifications: "… reference unit modifications determined to be relevant to the operator training program shall be implemented on the simulator within 24 months of the reference unit's modification in-service date or earlier, if warranted by a training needs assessment". Notwithstanding the regulatory framework for OTS' described above, safe and reliable operation of the NPPs is paramount. Providing plant operators with the knowledge and skills on new, sometimes complex, digital upgrades ahead of plant implementation just makes sense and is good industry practice.

2 REASONS TO IMPLEMENT DIGITAL UPGRADES ON SIMULATORS FIRST BEFORE PLANT IMPLEMENTATION

There are numerous reasons why utilities and DCS OEMs should consider implementing digital upgrades on simulators prior to plant implementation. The first compelling reason is that simulators are a perfect test-bed to perform closed-loop testing of digital upgrades. Today's simulator high-fidelity plant system process models provide an accurate replication of the plant's behavior under normal, abnormal and emergency conditions. With the use of either the full scope simulator (control room replica) or soft panels (virtual control room), the operators cannot only operate the DCS but also the rest of the plant for integrated testing purposes. Experience has shown that thousands of DCS deficiencies (for a complex system) can be identified early in the controls and Human-Machine Interface (HMI) using either the OTS and/or ES. This approach is viable for both existing GEN 2 NPPs and NNB plants. The benefits of first testing the digital upgrades on simulators include early identification of design deficiencies and the opportunity to test deficiency fixes earlier in the DCS life cycle resulting in lower project costs, less risk of delays during plant commissioning/startup (resulting in loss of generation costs) and all this without jeopardizing nuclear safety. The second key reason is to empower operators with the knowledge and skills to operate the new digital systems in the most realistic environment possible with realistic virtual plant feedback (closed-loop integrated system). The benefits of training operators early also include better acceptance of the new system by the operators. Better training may also prevent a plant transient or unplanned shutdown with more proficient and effective operators on the new system. Plant procedures (i.e. DCS commissioning/startup test procedures and revised plant operating procedures) can be developed, validated and corrected using the OTS and/or ES to ensure a smooth plant commissioning/startup. Furthermore, the plant startup can be rehearsed on the OTS to ensure the correctness of the procedures and to develop teamwork between operators, engineering, technicians, management, and others.

3 POSSIBLE DIGITAL UPGRADE IMPLEMENTATION STRATEGIES FOR SIMULATORS

There are three (3) primary simulator implementation strategies for the controls and related HMI in digital upgrades: stimulation, emulation and simulation. Each strategy has advantages and disadvantages that need to be carefully evaluated. Factors to consider include project strategy, plant design data availability timeframe and project schedule, DCS OEM Intellectual Property (IP) considerations, cost of hardware and software licenses, licensing restrictions, development and classroom simulators (portability) to supplement full scope OTS, configuration control and management (ease of plant changes implementation on the simulator), fidelity requirements, preference, etc. The simulator implementation can also be a hybrid solution meaning that the strategy for the controls and HMI can be different (e.g. simulated controls and stimulated HMI).

3.1 Stimulation

Stimulation involves using the same DCS hardware and application software as the plant. The DCS field inputs and outputs are replaced by simulated signals interfaced via either an Input/Output (I/O) system or a data link. The main advantage of stimulation is that it provides the highest functional and physical replication of controls and HMI. The main disadvantages of stimulation are the high cost of hardware and software licenses and that it prevents duplication of simulator platforms (development and classroom) without considerable investment. With a stimulated solution, the maturity of the DCS development must also be considered carefully.

3.2 Emulation

Emulation involves implementing the same DCS application software as the plant, running on a lower cost computer hardware. In the case of DCS controls, emulation is sometimes referred to as "virtual machine", "virtual simulation" or "virtual controller". The main advantage of emulation is that it provides the highest functional and physical replication of controls and HMI. The main disadvantages of emulation are the high cost of software licenses and that it is not always possible to implement depending on the DCS OEM or may not be cost-effective for installing on multiple simulator platforms.

3.3 Simulation

Simulation involves replicating the DCS functionality within the simulation environment. The main advantages of simulation include high-fidelity replication subject to data availability, inherent support of simulator commands, and controls and HMI can be modified very quickly independently from the DCS OEM. The main disadvantages are that it requires access to proprietary data from the DCS OEM and it requires more upfront testing and validation.

4 SIMULATION TECHNOLOGIES

4.1 Controls Simulation

Digital controls can be modeled as either graphical or non-graphical models. For graphical models, L3 MAPPS uses its Orchid® Modeling Environment (Orchid® ME). Orchid® ME allows for the creation of object libraries replicating the various control algorithms. Modeling schematics can be created either automatically from the plant DCS configuration files export or manually. Fig. 1 shows an example of simulated graphical controls.

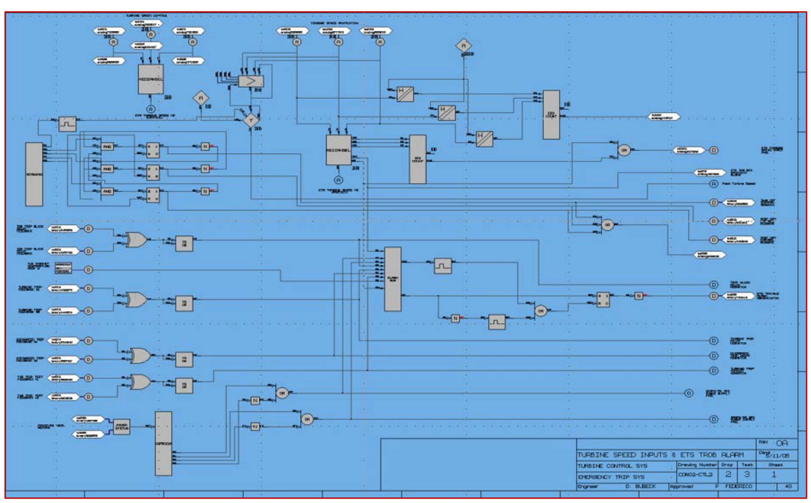

Figure 1. Example of Orchid® Modeling Environment Simulated Graphical Controls.

For non-graphical models, C or C++ code is either automatically generated from plant DCS configuration files export or manually coded.

4.2 HMI Simulation

Digital HMI can be simulated using L3 MAPPS' Orchid® Control System (Orchid® CS). Orchid® CS is founded on a real-time data acquisition and control system used in actual energy and naval systems. Orchid® CS is a flexible client/server application. The graphic pages can either be generated automatically from the plant DCS configuration files export (example shown in Fig. 2) or created manually with a powerful graphic editor. Orchid® CS includes database maintenance tools and supports trends (refer to Fig. 3), alarm lists, popups, etc. Orchid® CS supports all the required simulator commands (e.g. freeze/run, store/restore, backtrack/replay, etc.). Orchid® CS allows for high-fidelity reproduction of HMI due to its high level of customization.

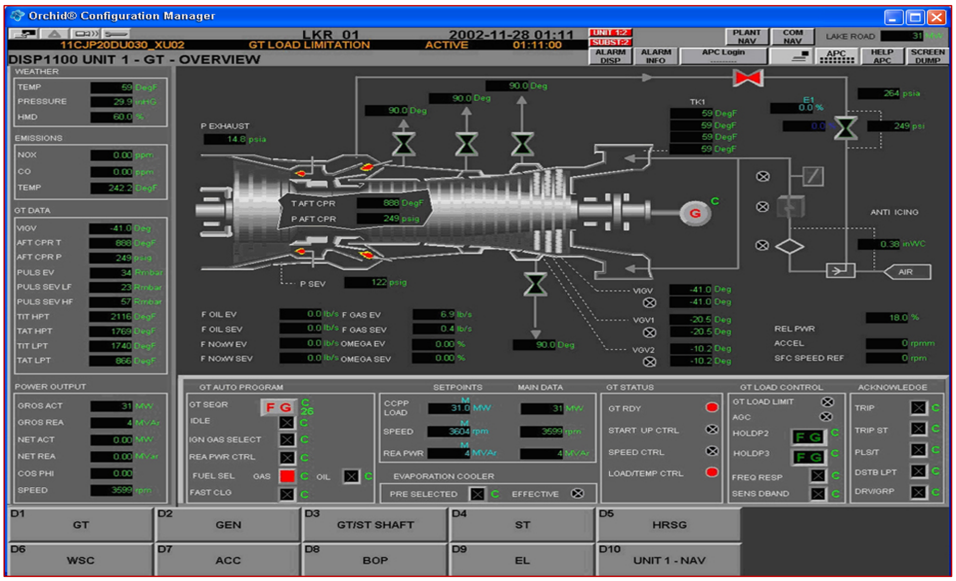

Figure 2. Example of Orchid® Control System Translated HMI.

Figure 3. Example of Orchid® Control System Trend Display.

4.3 Panel Instruments Simulation

For panel instruments such as digital controllers and simpler DCS HMI, L3 MAPPS utilizes its Orchid® Graphic Editor that allows the creation of photo-realistic interactive control room soft panels (virtual panels). Fig. 4 shows an example of soft panels with embedded simulated HMIs.

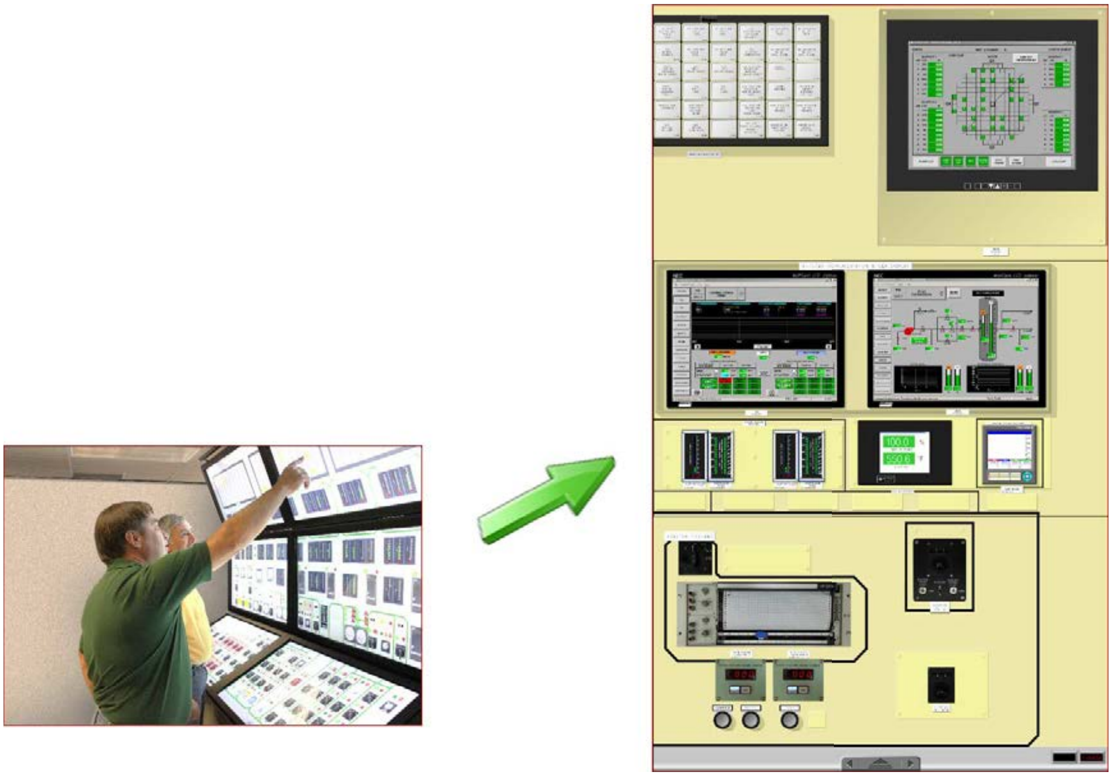

Figure 4. Example of Orchid® Graphic Editor Soft Panels Displayed on Touch Monitors with Embedded Orchid® Control System Simulated HMI.

5 CASE STUDY #1: ENRICO FERMI OFFGAS PLC SYSTEM

At Enrico Fermi NPP in Michigan, DTE Energy replaced the legacy offgas control system with a Siemens SIMATIC S7-1500 PLC. The purpose of the non-safety related offgas sytem is to process gases released, cool the gases and reduce radioactivity of airborne materials. The offgas system consists of several subsystems: recombiner, chiller, charcoal filters and ring water pump. For the controls, L3 MAPPS developed Orchid® ME graphical models (refer to Fig. 5) for the chiller PLC (controls simulated strategy). The control room instruments (HMI) were retained with only a few minor changes.

Result: In the course of the OTS Factory Acceptance Testing (FAT), prior to plant implementation, a design deficiency with the PLC chiller interlock logic was identified, corrected and the fix tested on the OTS before the system was installed in the plant.

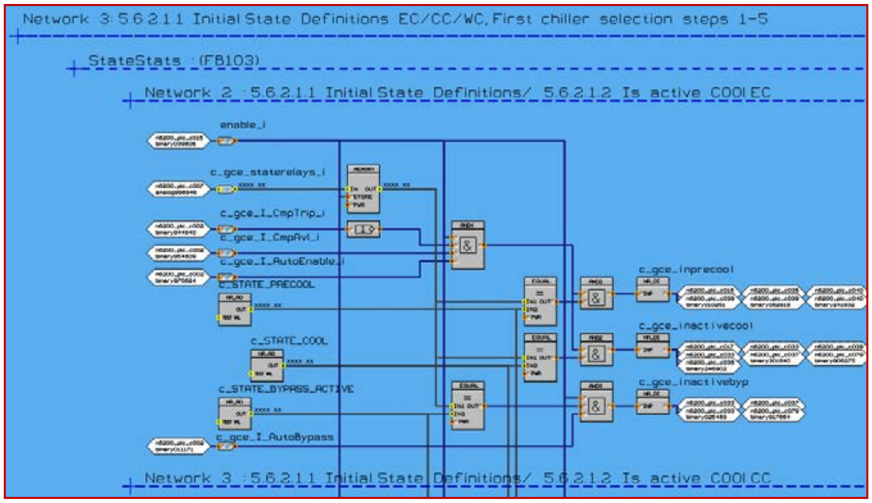

Figure 5. Enrico Fermi Simulated Graphical Controls.

6 CASE STUDY #2: CERNAVODA MAIN GENERATOR EXCITATION SYSTEM

At the Cernavodă NPP in Romania, Societatea Nationala Nuclearelectrica replaced the existing GE Generrex with a GE EX2100e main generator excitation system also referred to as the main generator Automatic Voltage Regulator (AVR) or exciter. L3 MAPPS created ROSE® (the predecessor of Orchid® ME) graphical controls (Fig. 6) (controls simulated strategy).

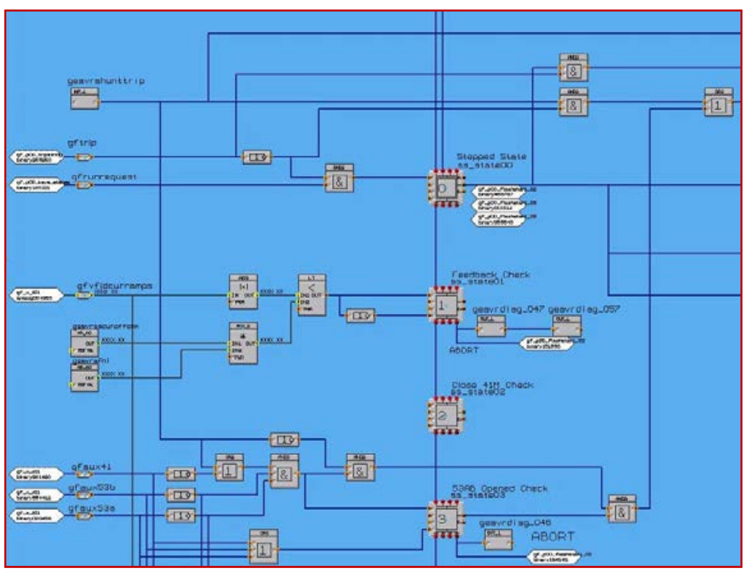

Figure 6. Cernavodă Simulated Graphical Controls.

For the full scope OTS, L3 MAPPS created a simulated HMI using Orchid® CS (HMI simulated strategy). As shown in Fig. 7 and Fig. 8, the simulated HMI look, feel and performance are very similar to the plant system.

Figure 7. Cernavodă Plant (left) vs. Simulator (right) Exciter Control Operator HMI.

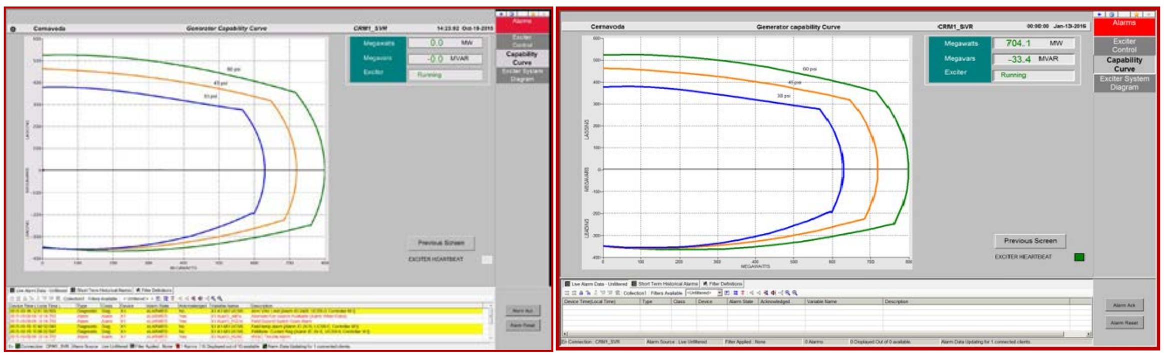

Figure 8. Cernavodă Plant (left) vs. Simulator (right) Main Generator Capability Curve Operator HMI.

Result: In parallel with the plant implementation effort, operators were exposed early to a fully integrated closed-loop high-fidelity system allowing the operators to get familiar with the new system.

7 CASE STUDY #3: CALLAWAY MAIN FEEDWATER CONTROL SYSTEM

At the Callaway NPP in Missouri, Ameren Missouri implemented a Siemens SPPA-T3000 main feedwater control system.

Ameren requested the capability to switch between the following three (3) configurations (single software configuration) during the transition to the new main feedwater control system: simulated legacy analog controls, simulated new digital controls and stimulated plant system (ES). In order to comply with this requirement, L3 MAPPS designed a “software switch” (refer to Fig. 9) to seamlessly transfer between the various configurations. The purpose of the ES was to fully test the plant DCS system using the simulator process models (closed-loop) prior to plant deployment.

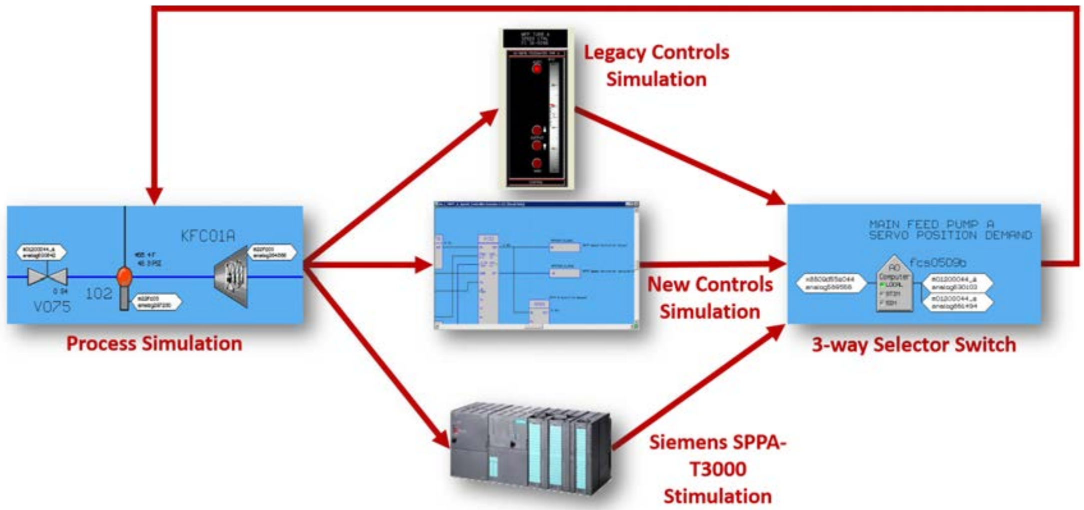

Figure 9. Callaway Software Switch.

For the OTS, the controls were translated to Orchid® ME graphical models as shown in Fig. 10 and the HMI was simulated using Orchid® CS.

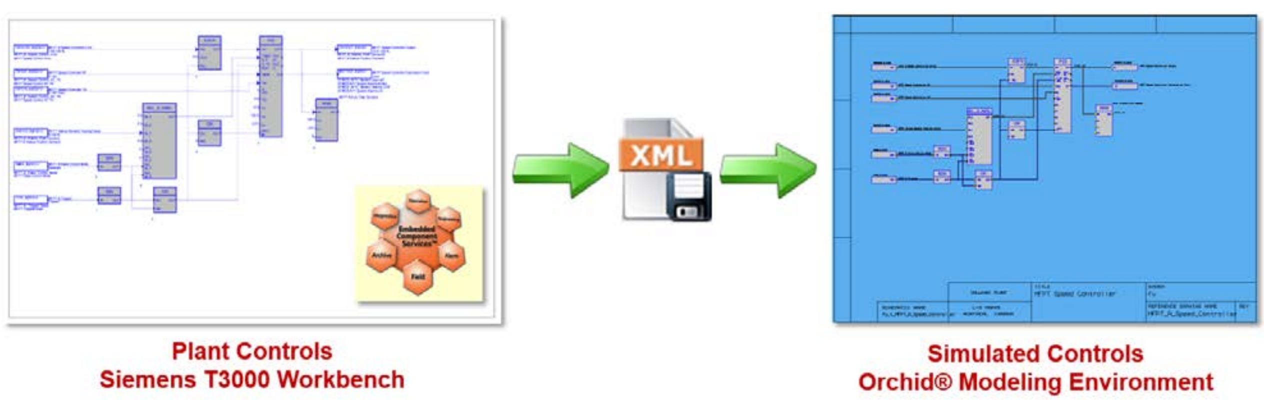

Figure 10. Callaway Plant (left) vs Simulator (right) Main Feedwater Controls.

For the ES, the controls and HMI were stimulated using the plant system. The simulation was interfaced to the plant system using a compact I/O system driven by L3 MAPPS Orchid® Input Output software. Fig. 11 shows the ES approach.

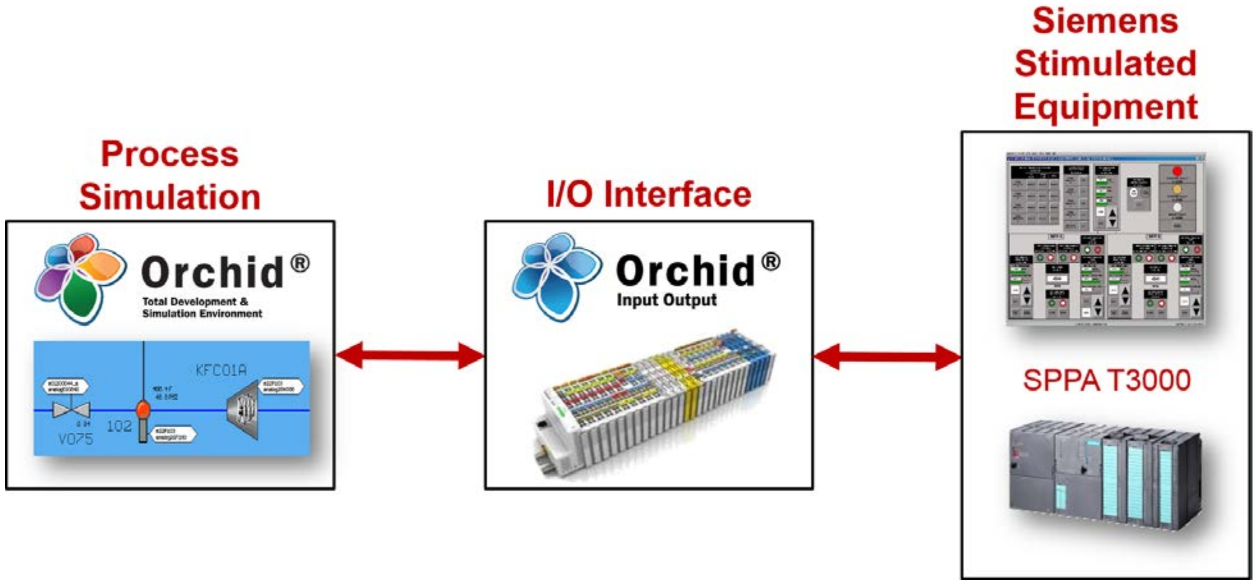

Figure 11. Callaway Engineering Simulator (ES) Approach.

__Result:__ The ES revealed multiple design deficiencies including reversed Digital Outputs (DOs), incorrect Proportional, Integral and Derivative (PID) settings and interlock issues, to name a few.

8 CASE STUDY #4: HONGYANHE PHASE I NON-SAFETY & SAFETY DCS

For the Hongyanhe Phase I (CPR1000) NNB plant in China, L3 MAPPS was contracted to develop a Full Scope Simulator (FSS). The Hongyanhe plant design includes a HOLLiAS non-safety related DCS and a MELTAC safety-related DCS. The non-safety related controls were translated to C code (controls simulated strategy) and the HMI was emulated (HMI emulated strategy) with approximately 280,000 signals exchanged between the controls and HMI. The safety-related controls and HMI were emulated (controls/HMI emulated strategy) with approximately 36,000 signals exchanged between the process models and the controls/HMI.

__Result:__ The use of the Hongyanhe Phase I dual-purposed OTS/ES helped identify, correct and test fixes for thousands of deficiencies before plant commissioning. The majority of deficiencies identified were related to DCS design errors and not simulator implementation (i.e. modeling and calibration) as shown in Fig. 12). The deficiencies identified on the simulator were used by the relevant designers to rapidly address the deficiencies in the actual plant implementation, thereby removing obstacles that may have arisen during the plant's commissioning/startup.

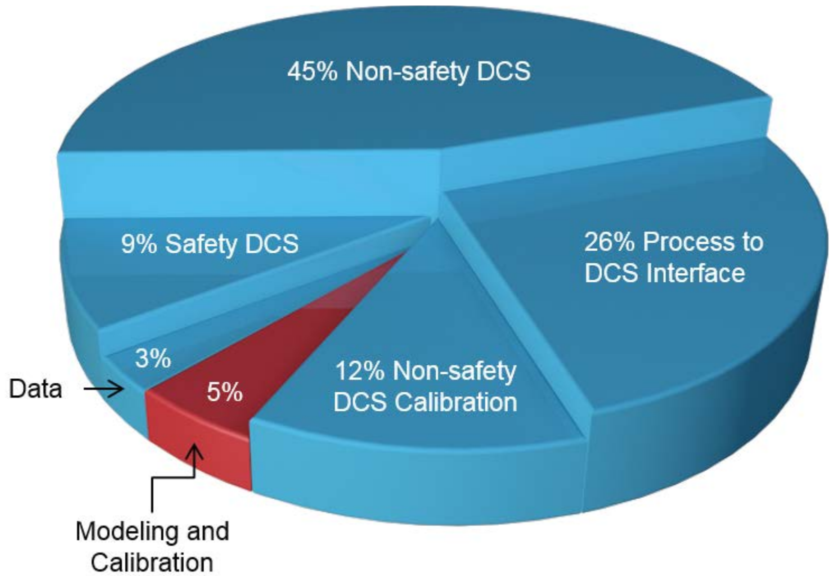

Figure 12. Hongyanhe Phase I OTS/ES Discovered Deficiency Categories.

9 CONCLUSIONS

Digitalization of legacy plants is progressing and will continue in the future based on the accepted principle of "Delivering the Nuclear Promise". Simulators can be used for early operator training and for plant/system design and Verification & Validation (V&V) helping identify and resolve design deficiencies before introduction in the plant. Experience has shown that thousands of deficiencies can be identified, corrected and resolved using the OTS and/or ES.

L3 MAPPS has extensive experience (40+ years) in implementing digital controls in legacy and NNB simulators using the different implementation strategies (i.e. stimulation, emulation, simulation, and hybrid). L3 MAPPS Orchid® simulation suite offers all the functions/features required for digital controls implementation on OTS (full scope and classroom) and ES in a fully integrated environment.

Several factors need to be considered before selecting a digital controls implementation strategy on the simulator as outlined in this paper. Whatever the chosen strategy is, it is clear that implementing digital upgrades in the OTS and/or ES early makes sense for the safe and reliable operation of NPPs.

10 REFERENCES

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