BWR MODERNIZATION PROJECT: INSTALLATION OF A NEW DIGITAL FEEDWATER CONTROL SYSTEM

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ABSTRACT

A European BWR plant carried out a relevant and pioneering modernization project regarding the Feedwater and Feed Pump Turbine Control System, replacing the legacy analogic control with the new General Electric MarkVIe digital system. This digital instrumentation and control modernization, motivated by obsolescence, had a great impact on the main control room and on the plant operation.

Tecnatom collaborated with the nuclear power plant in the project performing the following activities: early installation of the system in the full scope and classroom simulators, Human Factors Engineering (HFE) Verification and Validation (V&V), Simulation Assisted Engineering (SAE), design and implementation of cyber secure communication with the Plant Process Computer (PPC), operating procedures modification and plant operators training.

Those activities contributed to the success of the project that was completed during the refueling outage as planned. Scheduling HFE verification before the design freeze allowed the plant to modify the Human Machine Interface (HMI) to comply with the standards and increase safety without overcharging the project. SAE resulted in the reduction of costs and time during the system commissioning through the detection of discrepancies and improvements in the control, covering different plant scenarios. All the activities carried out in the simulators before the implementation of the system in the plant contributed to validate it and to build confidence in the new control among the plant personnel. New digital system communication interfaces with the PPC saved cable laying works and allowed future expansions.

Key Words: I&C Modernization, Digital I&C, HFE, SAE, PPC, Installation optimization, Cost reduction

1 INTRODUCTION

During the refueling outage a European BWR nuclear power plant, a relevant and pioneering modernization project was carried out to replace the legacy analogic Feedwater Level and Feedwater Pump Turbine Control System, with the new General Electric MarkVIe digital system.

Back in 2009, the plant had upgraded the existing turbine and pressure control to the GE MarkVI control system, therefore after the outage, the plant ended with both GE MarkVIe and MarkVI digital systems working together.

Tecnatom has traditionally played a major role in this power plant: maintaining, keeping update and operating the full scope and digital simulators; integrating the various digital systems at the main control room (balance of plant DCS, plant process computer); training the operators; reviewing the operating procedures; executing in-service inspection and tests and other activities supporting the utility and its subsidiary engineering company. Tecnatom collaborated with the nuclear power plant in this challenging project performing the following activities: early installation of the system in the full scope and classroom simulators, Human Factors Engineering (HFE) Verification and Validation (V&V), Simulation Assisted Engineering (SAE), design and implementation of cyber secure communication with the Plant Process Computer (PPC), operating procedures modification and plant operators training.

2 EARLY INSTALLATION OF MARKVIE DCS IN THER FULL SCOPE SIMULATOR

2.1 Background

It is the plant's strategy for any significant control room modernizations to conduct a DCS integration project in the full Scope Simulator, with the aim of testing and tuning the modification and allow the operators to train with the new digital system before it is installed in the plant.

The strategy followed during the installation of the new digital system in the full scope simulator was virtual stimulation. GE MarkVI and MarkVIe virtual controllers execute the same application code that can be downloaded to a physical controller that will be used in the plant. The GE HMI system for the simulator was equal to the one provided for Main Control Room and communicates seamlessly with the virtual controllers over UDH[1].

Software platform tools, such as GE Toolbox ST, GE Legacy Toolbox and CIMPLICITY, are available for interactively viewing, editing and downloading application code and operation displays.

This I&C upgrade to DCS was a great challenge and sharing the experience can be something profitable for others.

2.2 Phase 0: Changes to the existing turbine and pressure Mark VI control system

GE Turbine and pressure control was already present in the simulator (and Main Control Room) due to a previous modernization project, consisting of five virtual MarkVI controllers and three GE HMIs based on CIMPLICITY 6.1.

The new feedwater level control system (FWLC) and the feedwater pump turbine control system (FPTC) consisted of 3 MarkVIe controllers and a total of 9 GE HMIs, based on CIMPLICITY 8.2, under Windows 7.

The new DCS besides monitoring and acting on the feedwater control would be able to operate on the turbine and pressure control, and eventually replace existing GE HMIs that were based on CIMPLICITY 6.1 under Windows XP.

The table below shows the evolution of the Control System in the framework of this project.

[1] UDH – Unit Data Highway: MarkVI and MarkVIe controller Ethernet-based LAN network

Table I. Control Systems Before and After the Modernization

	Turbine and Pressure Control System	FWL and FPT Control System	Turbine and Pressure Control System	FWL and FPT Control System	Turbine and Pressure Control System
Before	GE MarkVI	HMI CIMPLICITY 6.1	Analogic	Panel Indicators	GE MarkVI
After	GE MarkVI	HMI CIMPLICITY 8.2	GE MarkVIe	HMI CIMPLICITY 8.2	GE MarkVI

The demanding training schedule of the simulator forced to maintain the existing turbine control HMIs during first phases of the project, avoiding panel works on that part until the last stage and focusing on replacing the FWLC and FPTC analog instrumentation by the new DCS.

In this phase, existing CIMPLICITY 6.1 HMIs and MarkVI controllers were configured to match their parameters with one of the feedwater CIMPLICITY 8.2 HMIs.

These works paved the way for a sequential development during the project, allowing existing MarkVI DCS to coexist on the same network with the new MarkVIe DCS and being fully operative until the last phase.

2.3 Phase 1: Installation of post-FAT feedwater level and feedwater pump turbine Mark VIe control system

MarkVIe control logics and CIMPLICITY operation displays resulted after FAT were used as starting point for this phase.

Three new MarkVIe virtual controllers were installed on the simulator and more than 700 i/o signals were mapped to simulator models. Two new desktop CIMPLICITY 8.2 HMIs and EWS were connected to UDH.

During integration tests, MarkVIe control loops were tuned, by performing bump tests, in the normal range of operation for each controller.

Some network overload led to a rationalization process of exchange rates for some of the data traveling through UDH. Exchange rates were modified for each case based on the consumer information needs.

At that point, legacy turbine and pressure GE HMIs and new FWL & FPT GE HMIs coexisted monitoring and acting on both MarkVI and MarkVIe virtual controllers.

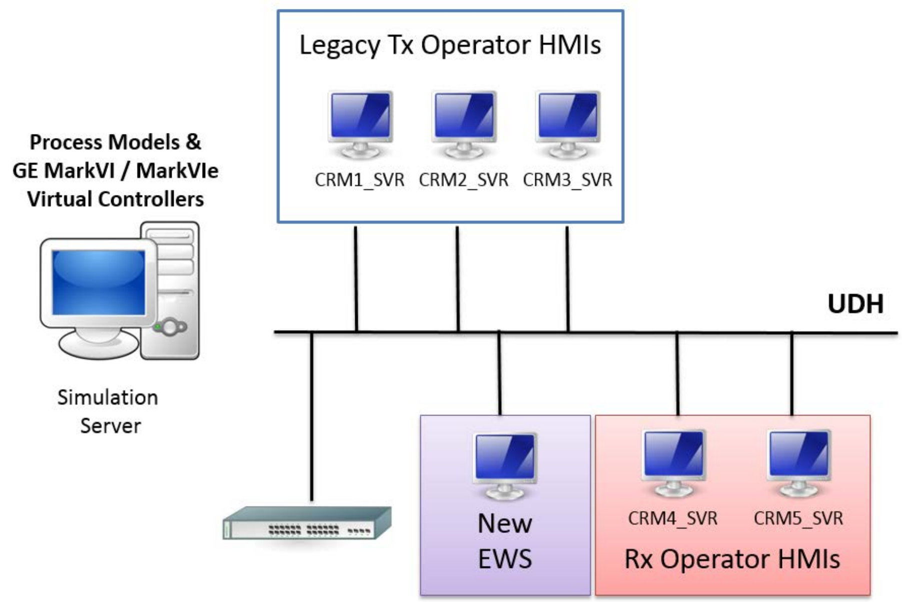

Figure 1. Simplified DCS architecture during Phase I

At the end of this phase, additional operating tests were performed, validating the system for initial training of the plant personnel.

2.4 Phase 2: Panel work, complete system validation and other activities

FWL & FPT analogic instrumentation was removed from simulator panels and replaced by three touch-screen panel-mount monitors for the reactor operator and one 56” monitor connected to the supervisor HMI. The turbine operator and supervisor had an additional desktop monitor each.

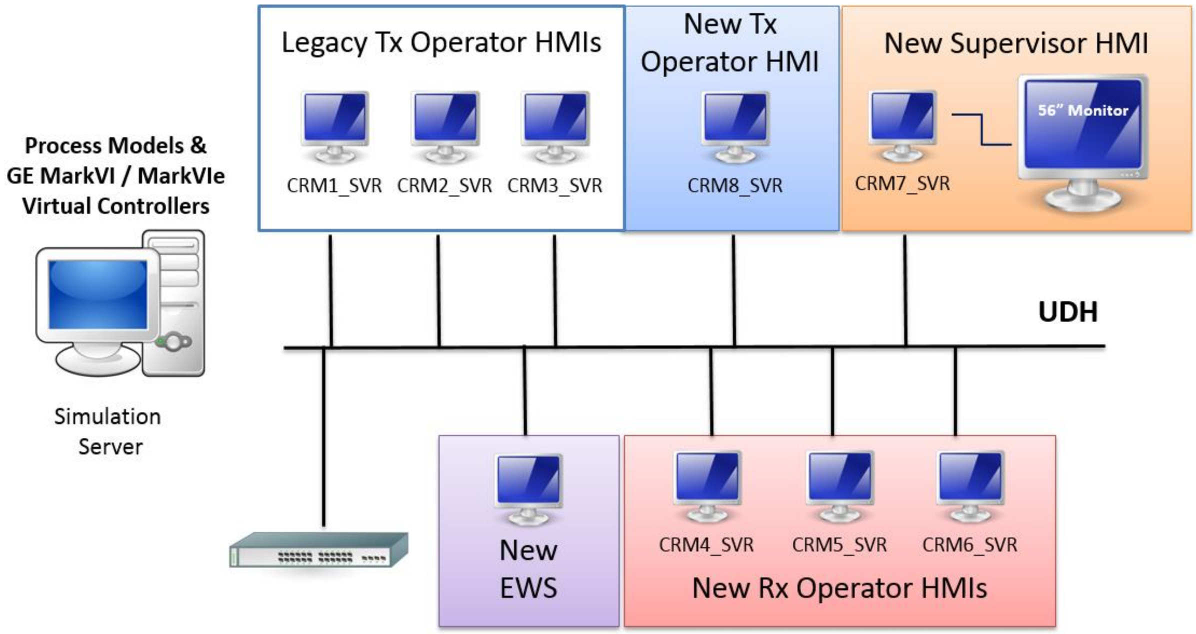

Figure 2. Simplified DCS architecture during Phase II

Within the scope of this project, Tecnatom collaborated with the nuclear power plant performing other the activities: Human Factors Engineering (HFE) Verification and Validation (V&V), Simulation Assisted Engineering (SAE), operating procedures modification and plant operators training. Those activities are briefly described in this paragraph.

2.4.1 SAE

After the installation and integration of the system in the simulation environment, the operating tests may be performed. In this case, a complete plant start-up, shutdown and more than forty transients related to the feedwater and turbo pumps were carried out. These tests allowed the detection of several discrepancies and the comparison between legacy and new control systems, provided valuable input for control fine tuning and system validation for training.

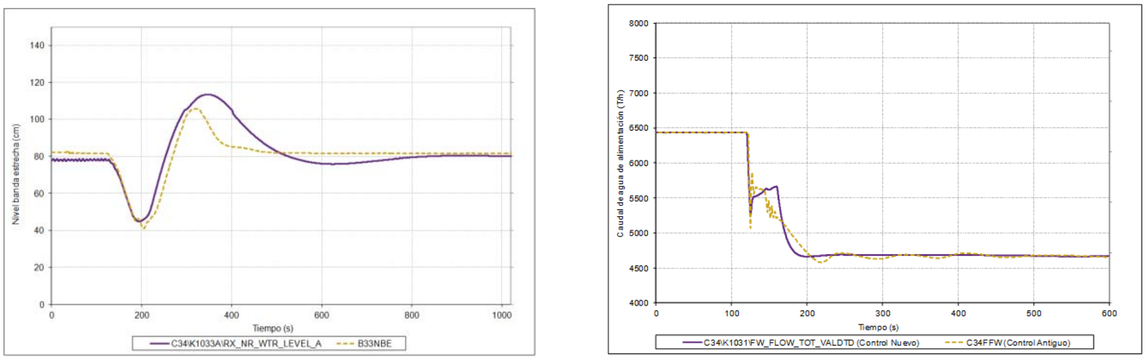

Figure 3. Comparison between legacy and new control system

2.4.2 HFE

I&C modernization projects usually impact on human machine interfaces (HMI) which should be evaluated from the human factors engineering (HFE) point of view in order to reduce the potential human error on operation. In this project, legacy analogic controllers on panels were replaced by digital monitors and touchscreens.

Human Factors Engineering (HFE) was carried out on HMIs installed at simulator, allowing the plant to modify and test operation displays to comply with standards.

Figure 4. Human Machine Interface in full-scope simulator before (left) and after (right) Phase 2

To evaluate the new HMI, the following verification and validation (V&V) activities based on NUREG.0711 were performed:

- Task verification
- Design verification
- Integrated validation (including 20 scenarios and involving three operation shifts)

HFE V&V activities results analysis allowed to identify and conduct HMI design modifications to optimize the operation of the system. Scheduling HFE verification before the design freeze allowed the plant to modify the Human Machine Interface (HMI) to comply with the standards and increase safety without overcharging the project.

2.4.3 Operating procedures review

Tecnatom reviewed and modified all the operating procedures related with the system including normal, abnormal and systems procedures. The new operating procedures, adapted to new DCS, were used for HFE, training and testing activities.

2.4.4 Plant operators training

Early installation of MarkVIe DCS in the full scope simulator allowed Tecnatom instructors to train the plant in the new control system before the implementation. Training covered different scenarios including the plant start-up.

2.5 Phase 3: As-built update

Changes made on the new DCS installed on the full-scope simulator after SAE and HFE activities were implemented by the utility and General Electric before the installation in Main Control Room.

After the refueling outage, the utility successfully carried out Site Acceptance Tests (SAT) during the startup of the unit.

In the simulator, last phase consisted of the replacement of turbine panel-mount monitors (4:3) and HMIs under Windows XP by new monitors (16:9) and CIMPLICITY 8.2 HMIs under Windows 7.

MarkVI and MarkVIe virtual controllers, as well as operation displays, were updated to match the as-built version resulted after SAT and plant start up.

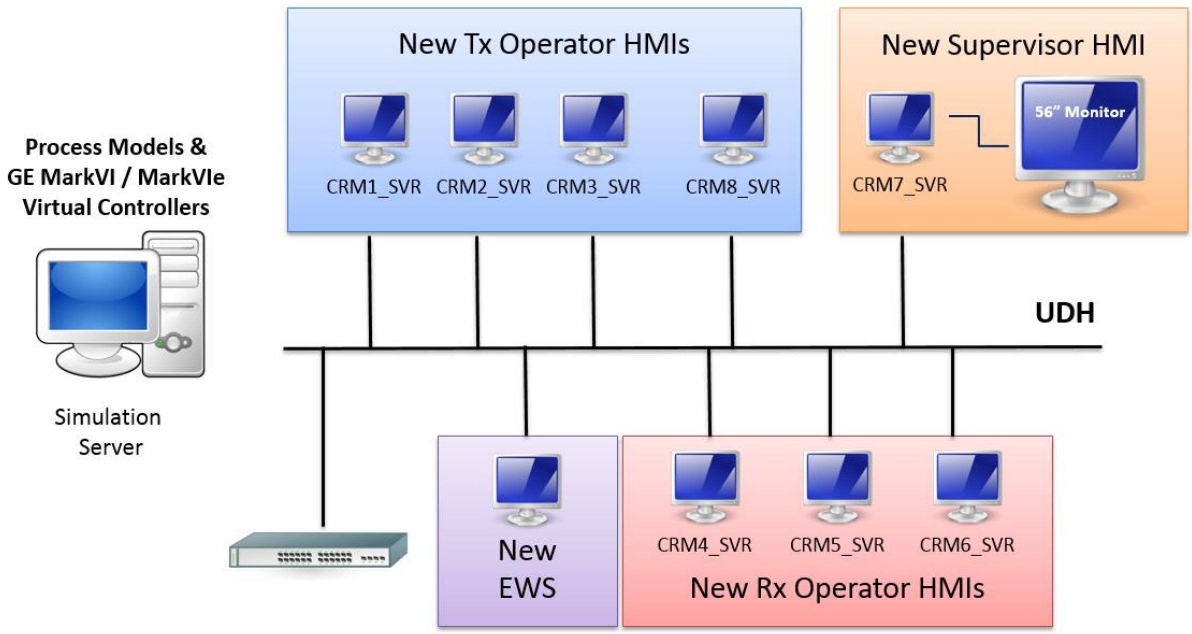

Figure 5. Simplified As-built DCS architecture

3 COMMUNICATION INTERFACES BETWEEN DIGITAL SYSTEMS IN MAIN CONTROL ROOM

3.1 Scope

During the first phases of the FWLC modernization project, the idea of a digital high-speed communication link between Mark VIe platform and the Plan Process Computer was carefully evaluated for the potential benefits it meant.

The benefits of a digital link are:

- savings in rewiring costs and reduction of the number of data acquisition cards for those field signals that are common to both systems,
- avoidance of saturation problems of cable trays and penetrations, and
- ease of maintenance and scalability.

Tecnatom engineers, as PPC integrators, designed, developed and deployed a solution, which allowed a two-way communication between both systems.

3.2 Solution Life Cycle

Several protocols were analyzed in the concept phase, being OPC the preferred technology, which is a widespread standard in many industrial sectors.

The solution was designed and developed per criteria of high availability. A dual redundant architecture was designed (both on data source servers and on target servers) with independent communication channels to avoid common cause failures that could compromise the overall operation of the systems.

Likewise, means for fault detection and mitigation guarantee digital communications with a maximum degree of reliability and robustness.

Once completed the development phase, Factory Acceptance Tests were conducted in Tecnatom facilities. The test platform was quite close to the target platform. It was comprised of real workstations from Tecnatom simulators, two GE HMIs and one PPC server, updated with the last configuration and software from site.

FAT successfully validated software integration within the rest of PPC processes, data transmission from and to GE HMIs, performance and rates and fault-tolerant controls.

During the outage and after the installation of new GE HMIs in Main Control Room was completed, post-FAT validated software was deployed on primary and secondary PPC servers. In order to comply with plant cybersecurity criteria, network segmentation between the two systems was achieved via firewalls and OPC communication was secured using tunneling technology.

Lastly, Site Acceptance Tests (SAT) were successfully conducted to validate the whole architecture, redundancy strategy and final data transmission rates.

In addition to the substantial reduction of time and materials, the implemented solution allows a high degree of scalability and easy signal reconfiguration without causing unavailability of both systems.

4 CONCLUSIONS

The commissioning and start-up of the new MarkVIe control system were successfully completed during the refueling outage, meeting all the schedules.

The activities performed by Tecnatom contributed to the success of the project. They resulted in the reduction of costs and time during the system commissioning through the detection of discrepancies and improvements in the control, covering different plant scenarios. All the activities carried out in the simulators before the implementation of the system in the plant contributed to validate it and to build confidence in the new control among the plant personnel.

The prior modification of the simulator allowed the performance of HFE verification and validation analysis, the training of operators in the new system and the review and validation of the operating procedures. New digital system communication interfaces with the PPC reduced the cable laying works during the outage which saving costs and time during the outage. The communication program considers future expansions. The execution of HFE verification before the design freeze allowed the plant to modify the HMI according with the standards without the need for additional funds.

In addition to the tangible benefits obtained from the development these activities, such as the reduction of costs and time during the system commissioning through the detection of discrepancies and improvements in the control, an intangible benefit was noticed as well. All the activities carried out before the implementation of the system in the plant contributed to build confidence in the new control among the plant personnel.

Tecnatom's approach for design modifications integrates I&C, simulation, HFE and plant operation is its differential factor and a clear added value to the utilities. To conclude, amongst the main keys to the success of the project, the close cooperation between the utility, its subsidiary engineering Company, General Electric and Tecnatom and the high fidelity and maturity of the full scope simulator may be highlighted.