Software-based Annunciator Replacement: A Tale of Two Projects

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Abstract

Annunciator upgrade projects are often included as parts of operating plant life extension projects as the systems are old and replacement parts are difficult to source. This paper contains case studies of the software-based annunciator replacement projects at the Westinghouse SNUPPS training simulator in Pennsylvania and the Axpo Beznau nuclear power plant in Switzerland. Software-based annunciator systems can offer a number of feature enhancements including improved readability and operator awareness, easy configuration, alarm suppression features, and alarm management at operator workstations. This paper provides an overview of each project and discusses advantages, challenges, and lessons learned from both annunciator-replacement projects.

1. Background

Westinghouse has been developing custom software-based alarm systems since the 1990s. In 2007, the Nuclear Automation division started work on a highly configurable, modular alarm system that would provide a reusable foundation for future software-based alarm systems. Project-specific user interfaces and functionality could then be added as needed to produce the final solution. The Shin Kori 3/4 project, an APR1400 nuclear power plant being built by KEPCO in South Korea, was the first project to use this software. The Alarm Presentation System (APS) was built on the Shin Kori code base and added many new features as well as enhancements to the architecture. The Axpo NEXIS (New Extended Information System) and Westinghouse SNUPPS (Standard Nuclear Unit Power Plant System) simulator projects discussed in this paper are based on the APS software.

2. Axpo AWARE Upgrade

The Beznau nuclear power plant is a two-unit site located in Döttingen, Switzerland that is owned by the Swiss utility Axpo AG. Unit 1 has been in operation since 1969, making it the oldest operating nuclear power station in the world. Unit 2 went into operation in 1972. A large modernization project was performed in the 1990s that included a new alarm system called AWARE. The NEXIS project involved upgrading the current control system to Ovation 3.5. Much of the project involved migrating existing displays, control logic, and nuclear applications to the new platform, but the AWARE alarm system, a custom alarm system developed by

Westinghouse, needed to be rewritten. The NEXIS project would be the first project to use APS as the basis for an alarm system upgrade. In addition to the AWARE upgrade, eight pairs of digital displays that showed the current value of key plant parameters were replaced with information-rich trend displays known as the Large Digital Display (LDD) system.

2.1 Original System Overview

The original AWARE system was a hybrid software/hardware alarm system that read process values and equipment status from the control system, performed alarm logic, and then displayed alarm messages on twelve panels mounted above the control board.
Alarm messages were displayed using a two line display similar to a cash register display. Eight plant parameters were displayed below the alarm panels using similar displays. Figure 1 shows the Unit 2 control room with the original AWARE system.

Figure 1 Beznau Unit 2 Control Room (before)

Figure 2 shows a photo of an AWARE alarm panel with two plant parameter displays below it. As the photo shows, the displays are not easy to read from a distance. Note how background color, nested borders, and labels were used to group alarm messages.

Figure 2 Original AWARE Panel

2.2 AWARE+ Overview

Axpo had two major goals for the new alarm system named "AWARE+". The first goal was that AWARE+ needed to replicate the existing AWARE functionality and layout (with minor changes) to minimize the need for operator re-training. The second goal was to make the AWARE Database Maintenance Utility (ADMU) faster and easier to use.

The AWARE+ hardware architecture was designed with availability and fault tolerance in mind. Ovation uses redundant Ethernet networks to ensure connectivity between computers. Redundant controllers execute the alarm logic. Redundant alarm servers monitor the Ovation data highway for alarms and provide independent video feeds to the monitors. The monitors themselves are the only non-redundant part of the system.

The AWARE+ upgrade replaced each AWARE panel with a large, high definition LED monitor. The original AWARE panels were one meter square. The alarm area was 650mm x 1000mm and the plant parameter area was 250mm x 1000mm. The 16:9 aspect ratio of the monitor meant that the size of the replacement monitor was constrained by the width of the original panel.

Axpo selected a 40" professional grade monitor that features redundant power supplies, a user-replaceable input module, and a terminal block that allows external control of the monitor. Digital outputs from one of the AWARE+ controllers selects which video input is used. Each alarm server supplies video to all twelve monitors using Matrox Extio2 video hardware. The Matrox hardware is comprised of two PCI cards in each server that send data over fiber to KVM extension boxes. Figure 3 shows the simulator control room as the installation was near completion.

Figure 3 Beznau Simulator Control Room (after)

The original AWARE server performed the alarm logic calculations and alarm presentation. For AWARE+, the alarm logic calculations and alarm presentation were separated. Alarm logic was migrated to control logic sheets that run on controllers. Care was taken to ensure that the logic was correctly migrated and that the calculations are executed in the same order as the original system.

The alarm presentation half of the AWARE+ software architecture uses a client-server architecture. The AWARE+ alarm server monitors the Ovation highway for alarms, controls the alarm horn, updates the alarm lists, and provides data to the AWARE+ clients. The Overview Client runs on the same computer as the alarm server and displays the alarm panels on the large monitors. The Support Client runs on operator workstations and provides additional alarm management functions.

Axpo wanted to improve readability of the alarm messages but the monitors were shorter than the original AWARE panel, so there was less vertical screen real estate to work with. Westinghouse worked closely with Axpo to revise the layout to maximize the size of the alarm message area. Figure 4 shows a close-up photo of the new AWARE+ panels plus the new LDD trend displays.

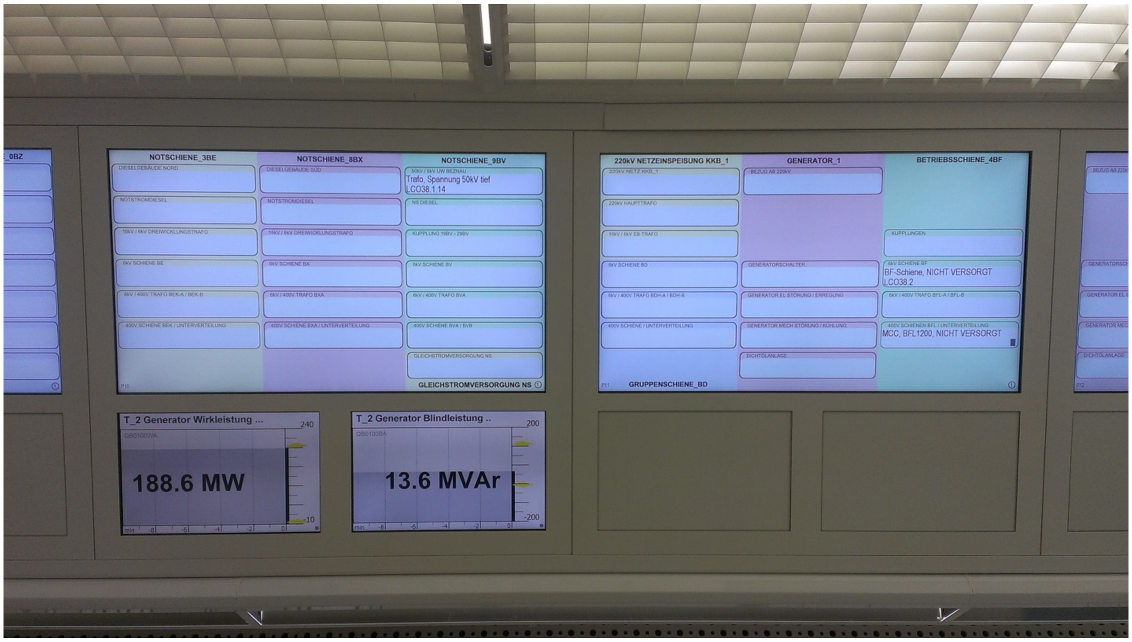

Figure 4 AWARE+ and LDD Close-Up

The Support Client was ported with only minor changes. The Support Client lets operators view a top level overview of all the alarm panels, view individual alarm panels, and drill down to view detailed alarm lists including a plant-wide history list.

Moving to a software-based alarm system requires consideration of failure modes and self-test functions. The original AWARE system had a test function that displayed a test message in each display, similar to a lamp test on a traditional annunciator system. The AWARE+ test function creates a test alarm that is used to verify that the alarm server is monitoring alarms, that the alarm sound system is working, that the silence and acknowledge buttons are working, and that the client software displays the test alarm message. Each monitor also has a heartbeat indication (blinking circle) that provides visual feedback that the display is being updated.

The large reduction in display-related hardware means that there are fewer places for the system to fail. The downside is that if a monitor fails, the failure affects all the alarms on that panel. The monitors have redundant power supplies powered by different trains, but the monitor itself could fail. The vendor reports that if the monitor fails, it usually is the input module which can be replaced in the field. The Support Client provides a backup in the event of a monitor failure. The rest of the video system is redundant.

2.3 AWARE+ Database Maintenance Utility (ADMU)

The original ADMU was slow and cumbersome to use. With alarm logic migrating to control sheets, the new ADMU only needed to manage alarm presentation settings. The new ADMU utility is a Java front end to a database that runs on an engineering development system.

Between the migration of alarm logic to control sheets and the removal of all the hardware and I/O needed to drive the displays, the data that needed to be managed by the ADMU was greatly reduced, making the application much simpler to use. Configuration files are generated by the ADMU and installed on the target platform. The background images for the alarm panels are vector graphics files (SVG) that are exported as portable network graphics (PNG) files for installation on the target platform.

2.4 Large Digital Display (LDD)

The Large Digital Display system replaced the eight plant parameter displays. The new LDD system uses eight 19" monitors to present an information rich trend. Two monitors fit nicely under a single AWARE+ monitor as shown in Figure 4. The LDD system is comprised of a single (non-redundant) server that reads process values and displays trends on all eight monitors. LDD uses the same Matrox Extio2 graphics hardware used by AWARE+. Two PCI cards are used to drive four monitors each.

Axpo worked closely with Westinghouse to develop the new LDD trend layout which includes point value, units, data quality, alarm state, point name and description, a 10 minute live trend, and high and low alarm limit markers. Operators use the LDD Config utility to control which points are being trended. LDD presets have been developed for each plant mode as well as other conditions.

2.5 Upgrade Evaluation

The migration of the AWARE alarm system was one of the customer's biggest concerns at the start of the project but the AWARE+ and LDD systems turned out to be highlights of the project. Alarm messages are much more readable which is especially important for AWARE+ because the alarm message shown in any given location changes with the alarm list content. The quieter background colors and simplified borders of the new panel layout also help the operator focus on the alarm message.

The information-rich trends in the new LDD system provide a significant improvement in crew awareness over the previous text displays. The ability to easily change presets to match plant state is regularly used as the number of LDD presets has more than doubled with the new system.

The original ADMU application had become a major frustration for the engineers maintaining the system. Although the engineers now use three tools to maintain the system (Ovation Control Builder, ADMU, and Inkscape), the process is faster and easier. Dynamic alarm logic diagrams make it much easier to investigate the source of an alarm and to test alarm logic during development.

3. SNUPPS Annunciator Upgrade

The Standard Nuclear Unit Power Plant System (SNUPPS) was an initiative to create a standard nuclear power plant design. The SNUPPS design is used at the Wolf Creek and Calloway nuclear power plants. Westinghouse built a SNUPPS training simulator in the 1980s that currently resides at the Westinghouse Waltz Mill site in Madison, PA. The SNUPPS simulator is used for training non-operations personnel from utilities and industry groups in basic pressurized water reactor (PWR) theory and operation. The Westinghouse training and operational services (TOS) group teamed with the simulator and human-machine interface groups to implement a simulator modernization project that started by installing Ovation 3.5.1 and replacing the annunciator system with APS.

3.1 Original System Overview

The original SNUPPS annunciator system was comprised of seven annunciator banks (6 rows x 134 columns total). The TOS group also wanted to replace the two banks of engineered safety feature actuation status (ESFAS) lights and the bistable status light block. Finally, the digital displays that showed reactor coolant system (RCS) T-average and pressure values were to be replaced with trends. Figure 5 shows the SNUPPS simulator before the upgrade.

Figure 5 SNUPPS Simulator (before)

3.2 New System Overview

One of the challenges of replacing annunciators with large monitors is determining the number and size of monitors that will fit in the available space. For the SNUPPS simulator, height was the constraining factor. The tallest monitor that would fit was a 40” monitor. The left, center, and right control board sections were not the same size, so the solution was to use fifteen monitors: 6 on the left section, 4 in the center section and 5 on the right section. Each monitor displays a 6x9 grid of alarm tiles for a total of 135 columns. Figure 6 shows the SNUPPS simulator after the upgrade.

Figure 6 SNUPPS Simulator (after)

In addition to the alarm annunciators, the ESFAS lights on the left panel section were replaced by a pair of 34” ultra-wide monitors. The bistable status lights and plant parameter displays in the center section were replaced by a single 34” ultra-wide monitor.

The SNUPPS simulator uses a different system design than the AWARE+ upgrade. A single alarm server monitors the Ovation data highway for alarm changes and supplies data to the clients. The large alarm monitors are driven by six small client PCs located behind the monitors. Each client PC drives two monitors using the HDMI and DVI-D outputs on the client PC. Three of the PCs drive a third monitor via a USB video extender. Additional fault tolerance could be provided by driving each monitor with its own client PC.

The ESFAS and bistable panels are driven by a pair of workstations. Figure 7 provides a closer view of the center section of the control board showing the new alarm tile, ESFAS, bistable, and trend displays.

Figure 7 SNUPPS ESFAS, Bistable, and Trend Displays

On the software front, the simulator plant model computer was updated to send the alarm signals that drove the original annunciators to Ovation. The alarm server monitors the Ovation highway for alarm changes. Unlike the Axpo solution that has one client driving all twelve monitors, each client PC is running an alarm panel client that displays the alarm tiles for the monitors it services. The alarm panel clients get data from the alarm server. The ESFAS and bistable panels are status lights (do not blink), not alarms, but are being driven by the alarm system. The ESFAS and bistable panels demonstrate the ability to have tile-specific font sizes and colors.

In addition to the alarm panel clients, the upgrade also includes a new Workstation Client that runs on operator workstations. The new SNUPPS Workstation Client merges the APS alarm list with the panel navigation features of the Axpo Support Client plus some SNUPPS-specific alarm panel software. The SNUPPS Workstation Client is described in the next section.

3.3 SNUPPS Workstation Client

The SNUPPS simulator currently has a single Ovation operator workstation with four more workstations planned. The SNUPPS workstation client provides a number of features including easy access to alarm response procedures (PDFs), manual alarm suppression, tabbed alarm lists, access to Ovation MMI applications and an operator experience log.

The workstation client provides a top-level view of the fifteen alarm panels. Each of the mini alarm panels is dynamic and exactly matches the state the monitors. The operator clicks on a panel to drill down to the Panel view. From the panel view, the operator can view a list of the active alarms. The toolbar contains buttons for panel navigation, silencing the horn, system test, and displaying various alarm lists. The workstation client provides a redundant view of the alarm tiles in the event of a hardware failure, making each operator workstation in the control room a backup to the large alarm monitors.

3.4 Upgrade Evaluation

As with the AWARE+ upgrade, the new alarm tiles are easier to read, especially from the SRO desk. The alarm tiles now use colors to indicate alarm priority (red=high priority, yellow=normal priority, green=return to normal). When an alarm tile is active, the text is drawn in a bold font to make it easier to read and as a secondary indication that it is in alarm.

Most of the alarms do not require manual reset when they return to normal, but over 100 alarm tiles do require manual reset. The old system used reflash to indicate the return to normal condition. The new system displays the tile with a green background making it much easier to tell active alarms from returns. Instructors report that it is much easier to tell the difference between the different ESFAS status light states (gray=normal, white=actuation successful, amber=actuation failed) with the new system.

One of the upgrade requirements was that the alarm tiles must maintain their original row and column position. A side effect of the upgrade is that the grouping of related annunciators into banks in the original layout was lost. The alarm tiles closely maintained their original position on the control board with only minor shifts, but the small breaks between monitors do not match any functional grouping. Instructors noted the differences after the upgrade but quickly adapted to the new system.

The instructors also realized that their training material needed to be updated to reflect the new system. They can no longer simulate a burned out light bulb to keep a specific annunciator from lighting, or failing a relay to indicate a false positive alarm. Software-based alarm systems don't fail in the same way as traditional annunciator systems, so simulated sensor failures should be used to force individual alarms on or off. New malfunctions that simulate monitor or client PC failures should also be considered.

4. Conclusions

By all accounts, both annunciator replacement projects were unqualified successes. The customers and end users for both projects were very satisfied with the upgrades. The monitors provided improved readability of the text which was particularly important on the AWARE+ system. The use of color made a marked improvement to the SNUPPS alarm system.

The AWARE+ system shows how robust a software-based alarm system can be implemented, albeit with the cost for premium, redundant hardware. The SNUPPS solution shows how inexpensively a software-based solution can be implemented. The alarm management client at operator workstations adds helpful functionality while providing a backup to the alarm monitors. Careful tuning of the software can minimize the effect of latency due to the distributed architecture.

It's no secret that operators like trends and the addition of information-rich trend displays that can be read from anywhere in the control room was a big success on both projects. Operators report that the trend displays were perhaps the biggest improvement because they provided immediate access to information that was not available before.

Finally, software-based alarm systems can fail in different ways than the hardware-based annunciator systems they are replacing. The large reduction in components means there are fewer things to fail, but the effect may be greater when a failure does occur. Self-test procedures need to be revised to exercise the new system as a simple lamp test no longer applies. Simulator training scenarios also need to be updated to reflect the change in failure modes.

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