OPERATING DISPLAYS – NEW CONCEPT: HIGH PERFORMANCE DISPLAYS

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ABSTRACT

New control rooms in Nuclear Power Plants using digital Distributed Control System (DCS) operated with software displays, are providing thousands of signals to the operating crew. When an event happens, the Flood of information provided to operators could obscure the initiator event increasing the operator response time, work load and complicating the selection of the actions to be performed. There are some initiatives that are trying to minimize the “avalanche effect” as the alarm engineering filtering and prioritization or diagnostic displays. Likewise, new control rooms are lost the availability to know the plant status just with a quick glance to the panel indicators. Regarding Small Modular Reactors, where in some cases four operators should monitor and control twelve reactors, these problems are even more significant. The challenge is to find a solution, based on current digital systems, that supply information to operators in order to prevent events and take early actions to minimize or avoid any unexpected incident.

In order to minimize human errors, Tecnatom has developed a specific set of displays, called “High Performance Displays” (HPD) based on objectives, work environment limitation, and non-anticipated events. These displays are being design following the HFE standards: applying the NUREG-0711 [1] elements to identify the information that they have to content and the NUREG-0700 [2] to design the interface. The function of these displays is monitoring the plant situation in a way that the operators are able to recognize any potential event at a simple glance but controlling thousands of signals through pattern recognition, symmetries, regular polygons and colors. The objective of the HPD is to provide an integrated function minimizing the tunnel effect and reduce the workload during the diagnosis phase. Moreover, HPD enhance operators to take the right actions to anticipate the response to any event, even avoiding it, if possible

This paper analyzes how HPD’s have been design as well as presents the results of a preliminary validation of their capabilities. The preliminary validation is a reduce validation in a full scope simulator running two representative scenarios of abnormal and emergency operation. The analysis is focused on the first stage of the event, i.e. the detection phase, HPD’s have been installed in a generic full scope simulator of a nuclear power plant, digital controlled. Both scenarios have been performed by two different operator crews. The first operator shift has worked with the conventional human machine interface, that is, displays similar to the ones currently installed in existing nuclear power plant with digital control. The second crew, reproduce the same scenarios but with HPD available. The studio collects preliminary data in order to compare results, draw lesson learned from the experience to improve HPD design, and find solutions in terms of reducing human errors, human workload, and increase the availability of the plant.

Key Words: HFE, digital, displays, operation, validation

1 INTRODUCTION: WHY HIGH PERFORMANCE DISPLAYS?

The main role of the Nuclear Power Plant (NPP) operating crew is the process of decision making and problems resolved. The tasks, in a complex system as NPP is, have difficult solutions. It has been resolved during years by means of a huge panel with several instruments representing the plant mimic layout, helped by a system alarms. Nevertheless, for new designs, this model has been abandon and it has been adopted a new concept based on operating displays avoiding to use hardware instruments. The reason is evident, it is the same approach as people are follow in their houses, who is currently using mobile phones with key? Smart phone is the interface as well as operating displays are the NPP operating interfaces. We can discuss the advantages and disadvantages of operating displays versus hardware instruments for instance, the obsolesce, flexibility, etc, but the reality is that, new operators are more comfortable with operating displays, as their cell phones, than conventional instruments. It is what it is, so we must work considering this interface as the only one currently accepted.

Digital interfaces have a remarkable advantage, they are easily adapted, it is not needed a radial saw for including improvements in the interface. It allows to collect lesson learned from operators and provide interface upgrades minimizing human errors, identifying any abnormal / emergency situations quickly, and approaching the operating decision more and more to the right ones in right moment.

Working in this concept, and based on Tecnatom experience designing more that twelve digital control rooms for nuclear power plants, we were worried on studying something that the current operation concept, based on operating displays, it is not completely resolve. How are we sure that the operator knows exactly plant situation? Using the traditional big consoles with hardware instruments, it was easy, the operator just needed to perform a brief sight on the panels to know which train of each system is working and where is located an abnormal alignment.

The conformist operators, answer this question, helping on the alarm system. It is true that the alarm system has been design to annunciate any important event to the operator and to drive them to operate based on symptom. But it is also true that the alarm system has some weakness:

1. They are very dependent of alarm setpoints. In several situations, a standard alarm setpoints for one specific indication is not useful. You can add in new alarm system as much setpoints as the operator wants, but which is the right for each scenario? Sometimes, when an alarm appears, it is too late for avoiding further consequences.
2. Digital systems produce thousands of alarms where it is difficult to know the root case in a short time. For it, we are working in filtering and prioritization engineering analysis, but is it enough?

High Performance Displays (HPD) is a Computerized Operating Support System (COSS) developed based on covering and answering the questions and concerns written above. They have been created for providing more support to the operation, reducing the time response, the operator stress and increasing the knowledge of the plant status. They have not been designed with the intention to replace, or to add, more functionality to any existing system.

2 HIGH PERFORMANCE DISPLAYS: DESIGN PHASE

HPDs, as any regular operating displays, have been designed following the Human Factors Engineering (HFE) standards accepted by US Nuclear Regulatory Commission, that is, mainly based on NUREG-0711 [1] and NUREG-0700 [2] and their associated standards and guidelines.

HPD is a graphic interface display based on big monitor where is shown the information needed for supervising the plant status. The process that we have followed for obtaining a list of information to be displayed is summarized in the following points:

1. Selection of Functions to be monitored. These functions cover normal, abnormal, and emergency operation. Including as normal operation surveillance, maintenance and testing procedures.
2. Definition of different scenarios and operation modes for each defined function.

3. Allocation of Functions, that is assigning the function to personnel and / or machine (automation)
4. Task analysis. Definition of the tasks and activities to be perform from HPD in order to perform all functions which the display has been designed

The output of the steps listed above is a table including the minimum information to be displayed for achieving with designed function. Collecting this information in a conventional approach, it is obtaining a kind of displays as shown in Figure 1 “Conventional Display”. Conventional approach refers to a kind of displays, following NUREG-0700 [2] recommendations, where is allocated the requested information with standard shapes, that is, valves, pumps, read-out, … icons.

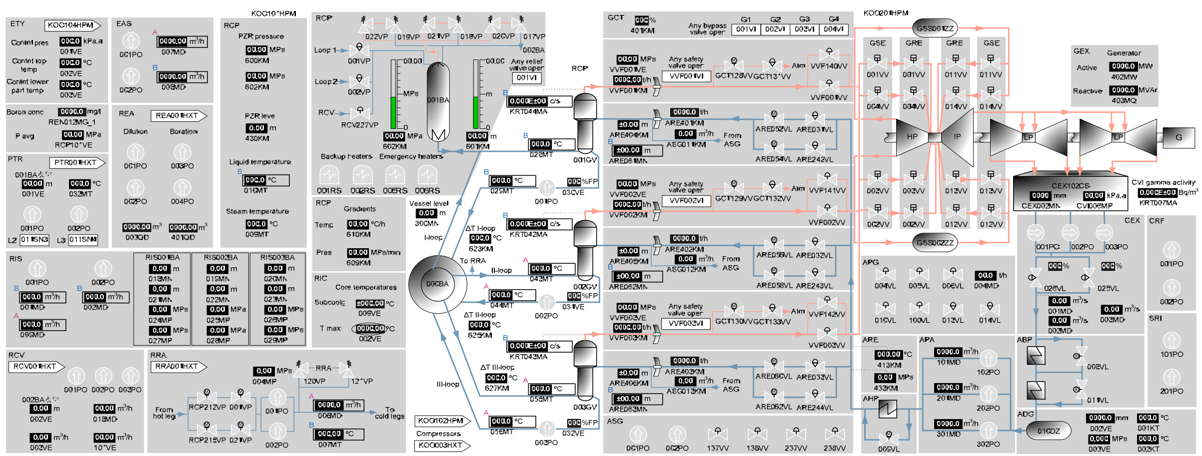

Figure 1. HSI Conventional Display

It is a good approach because it is included the most important information which allows to operating crew to have a clear idea about the plant status. Moreover, when it is designed with the functionality of changing the color when a parameter or a component status is alarmed. Actually, HPD does not supersede conventional displays but complements them.

Now is time to talk about how is designed HPD. The goal that HPD tries to meet is to allocate the limits, critical elements, and complex system plant relationships to Main Control Room, and making them evident and perceptible. For that, the first step is to use the information obtained from Human Factors Engineering analysis and design as the first input. The second step is to use an specific methodology developed by Tecnatom and based on Ecological interface Design technology.

The methodology is based on three main principles:

1. Work Environment. It consists in a structure methodology which is able to discover the limit values, parameters, and the relationships of the analyzed system and should be included in the interface. It is analyzed independently of any operator, automatism or task, therefore, the results have an appropriate answer in all kind of scenarios, no matter they are known or unknown events.
2. Abilities, Rules and knowledge stage. The second principle of the process consists of mapping extracted by HFE analysis and work environmental results. In this step, the methodology is based on classification of the abilities, rules and knowledge which classify and analyze the operator crew behavior according to cognitive load that each activity requests.

3. Situational awareness. It could be defined as knowledge status or mental model of the operator has in the work environmental in a specific task or event. Situational awareness can be divide in three levels:
   a. Perception of the environmental elements: Detection of perturbations (low level)
   b. Comprehension of the current scenario. Event interpretation (medium level)
   c. Next future status, scheduling and taking decisions and actions (high level)

When it is applied the methodology on the general plant supervision function, the equivalent displays as shown in Figure 1, but using HPD style, is the one shown in Figure 2 “Example of HPD for plant supervision”

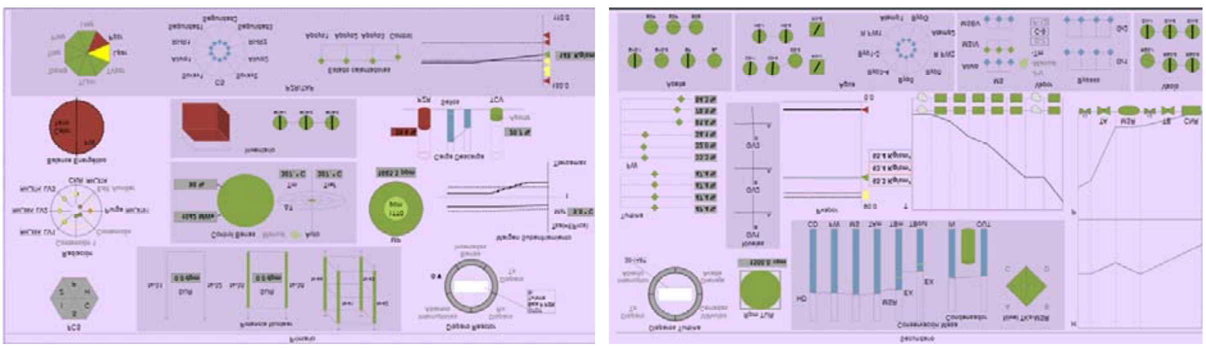

Figure 2. Example of High Performance Displays

3 HOW IS WORKING HIGH PERFORMANCE DISPLAYS?

The interfaces design following the methodology explained in these lines, have as a purpose to minimize the operator work load, especially in non-familiar scenarios where the stress of the operator increase at maximum. HPD gets it helping to the operating crew in the decision making and solving problems in critical situations.

The displays configuration plays a very important role. It is supported by the following variables:

1. Position on the display. Displays are shorted by a top-down hierarchy, where at the top are represented the critical parameters and moving to the bottom the consequences of the critical status
2. Size. The size of the shapes are directly related to the importance of the parameters
3. Brightness. Brightness, blinking or flashing are tools for calling the operator notice
4. Color. Color represents the status of the function observed
5. Orientation. The orientation provide to the operators how is evolving any event
6. Shapes. Shapes is complementing the orientation, that is, shapes help to the operator to understand the evolves of the event. Regular shapes represent normal status and the opposite, irregular shapes represent abnormal situations

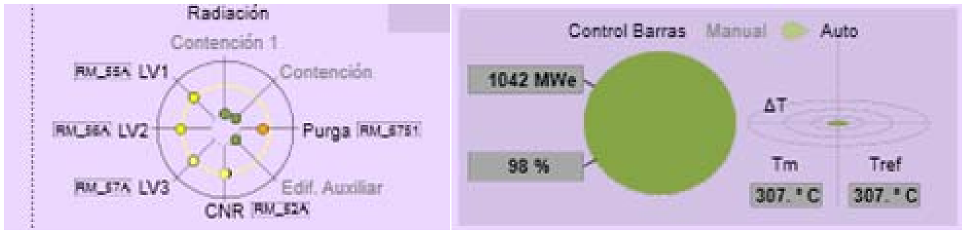

Figure 3. Examples of the way to display critical parameters

Figure 3 shows some examples how is represented some critical parameters of the plant status. The picture on the left represent the radiation surveillance in non-radioactive systems as contention or Balance of Plant are. Normal status should be represented as perfect circle with the small balls in green and closer to the circle center. Abnormal situations, the balls are moving to the external circle and changing the color from normal status represented by green color, to red color which represents alarm status.

This way of representation allows to the operating crew to know if there is an abnormal status, where, and the distance to the normal and alarm setpoints.

Picture on the right in figure 3, represents the control rod position related to electrical and nuclear power.

4 PRELIMINARY VALIDATION

The preliminary validation was performed in order to know if High Performance Displays really provide advantages versus conventional displays, in which situations and which could be their benefits. This experiment has used, as platform test bed, a generic full scope simulator of PWR-3 loops plant with more than one hundred of operating displays. It is quite similar to the ones used by operators training, so the results could be acceptable.

For it was prepared four scenarios from 100% of nuclear and electrical power where some events happened. All of them were scheduled with small severity, because the HPD developed by Tecnatom has been designed in order to cover the space from normal to abnormal operation before it is detected by alarms setpoints or any system automatic actuation. It is in this space where non-important event could derivate to an emergency situation or in the best of the cases could carry on a long shutdown for plant repairing and system cleaning.

The scenarios designed for the preliminary validation are:

1. Control scenario without malfunctions
2. Main Condenser tubes leakage
3. Small primary leakage from Reactor Cooling Pump seals
4. Small leakage in the tubes of the steam generator

The actors of this experiment were two Shift Supervisors. The scenarios were prepared with and without HPD. One supervisor worked with HPD, then the other without HLD. For the following scenario, the supervisor was shifted, that is, the one who operate with HPD was forced to operate with the interface without HPD. This way presents results independent to operator abilities.

Summarizing, all scenarios were performed by both supervisors. The following table shows the sequence of the scenarios by each supervisor.

Table I. Sequence of Scenarios

	Shift Supervisor 1		Shift Supervisor 3	
Scenario	**With HPD**	**W/O HPD**	**With HPD**	**W/O HPD**
Control scenario without malfunctions		E-1	E-8	
Main Condenser tubes leakage	E-4			E-5
Small primary leakage from Reactor Cooling Pump seals		E-2	E-6	
Small leakage in the tubes of the steam generator	E-3			E-7

The scenarios were defined with low severity, i.e., The scenarios were defined in order to avoid any abnormal alarm during the first half hour running. The reason why this restriction is due to the operation modes to be tested. As explained in paragraphs above, HPD are being designed for provide information to the operator before abnormal and emergency situations in order to take early actions to avoid worse plant status.

The results of this preliminary validation were not a surprise, Supervisors operating without HPD, did not detect any event till alarm system oriented them. At the opposite way, supervisors detected in an early stage, all events when the operation was based on HPD.

Specifically, the result of the experiment is that all plant conditions were detected in both cases. When the operator had available High Performance Displays, this detection was done few minutes after the malfunctions were introduced. When the supervisor didn't have HLD for supporting the operation, the even was not detected until an alarm alerted the operator, but after it, they clearly identified the specific event and run the right operation manual.

The reason why HLD helps to the operator to detect in an early stage, is due to how is designed the interface. The best way to understand these results is to compare the different displays that the operators had available when test was performed.

For understanding better, it is important to watch the same information as the operator could check. Figure 4 shows the appearance of HPD during 100% without any malfunction.

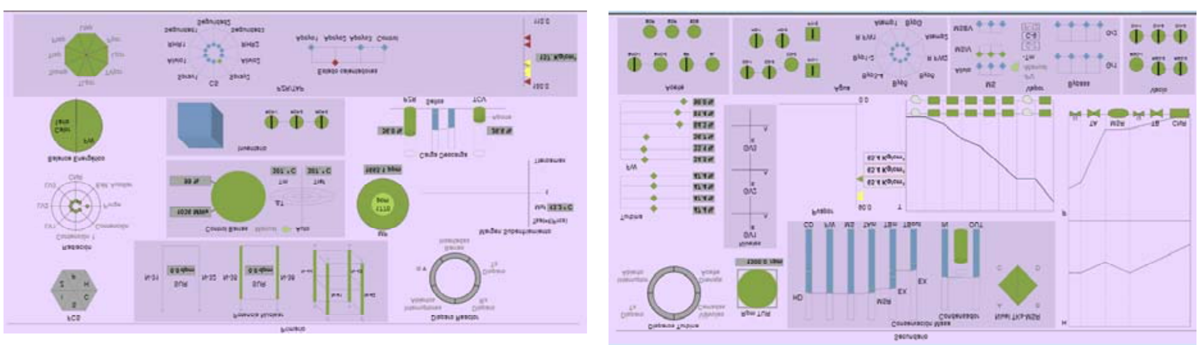

Figure 4. High Performance Displays at 100% of Power and without any abnormal event

As easily could be checked in figure 4, 100% is represented in HPD as green or blue color, but not yellow, orange or red, regular shapes as they are circles, pentagons, or rhombi.

For instance, after small steam generators tubes leakage, where primary water from reactor coolant circuit is abnormally moving to secondary circuit, the standards displays is showing the information as detailed in figure 5:

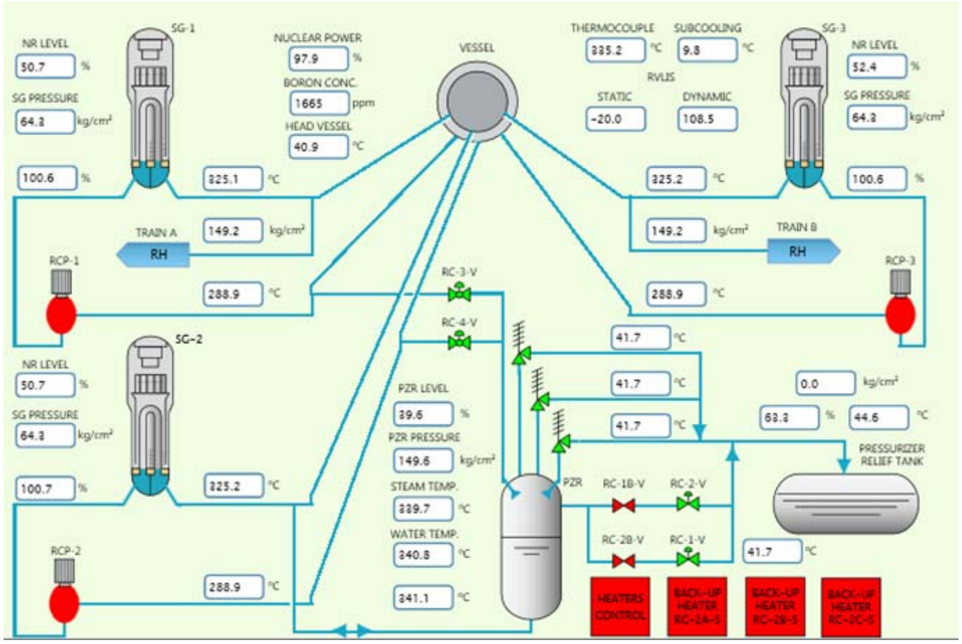

Figure 5. Regular displays during Steam generator small leakage

In absence of alarms, and taken into account that it is not the only operating display where the operator is checking the pant status, it is difficult to know that there is a small problem that can derivate, if it is not correctly solved, in an event with external radiation emission, i.e., the worst accident.

It is remarkable that the display of figure 5 shows clearly the event. Analyzing some parameters, the operator could figure out what was happening. The following parameters variation define the event:

1. Nuclear Power. The power is below 100%, it is in 97,9 %.
2. Steam Generator level. The level of steam generator 3, is a little be higher than the others two. Steam generator 1 and 2, are stabilized in level 50,7%, however, the level of steam generator 3 is 52,4%.
3. Pressurizer level and pressure lower than the normal operation but they are being compensated by pressure regulators, that is pressurizer heaters. The alarm associated to the heaters on, are the alarms which alert to the operator to take actions. Before it, the operator did not identify any problem in the plant.

The same event, but now showed by HPD is represented as follows (figure 6). The display has changed its aspect, from homogenous shapes and colors to changes which clearly alert to the operator

1. There are some yellow, orange and especially red color
2. The shapes are not regular, for instance, the cube is not filled up
3. The points have not been uniformed distributed

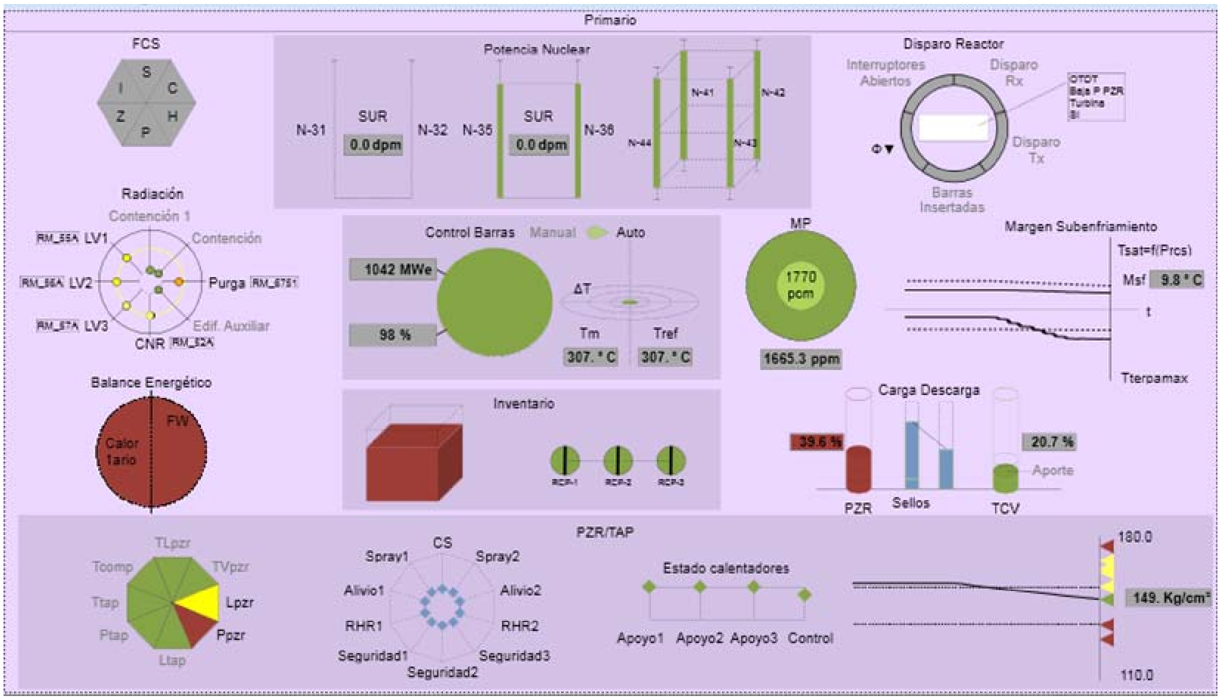

Figure 6. High Performance displays during Steam generator small leakage

5 CONCLUSIONS

The experiment demonstrates that supervising with conventional software displays the operation is safe, i.e., there is no any situation where the safety is compromised and it is easy to track the event evolution. On the other hand, supervising with High Performance Displays add an important value in terms of making early decisions to avoid more complex events. In all scenarios tested operating with HPD, the supervisors identified the malfunctions in the early stages and took the right decision to avoid any SCRAM.

The results of the experiment conclude that HPD met the function which they were designed, take the right decision in a short time. In terms of availability, because of the early detection, operating with HPD could avoid long period shutdown, for instance, cleaning a system contaminated or even avoiding safety injections by means of a quick isolation of the affected system.

6 ACKNOWLEDGMENTS

Thanks to the investment group who worked in this project and developed a detailed methodology and the product which could improve the safety of the nuclear power plants operation and could do it more competitive by means of reducing maintenance costs and evitable SCRAMs.

7 REFERENCES

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