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Integrated Overview Display Concept for Multi-Module SMR Supervisory Control

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1. Introduction

Small Modular Reactor (SMR) deployment is frequently coupled with a multi-module control room concept, where a single crew supervises several reactor modules concurrently. Compared with single-unit operation, supervisory monitoring must balance attention across modules while still enabling timely response to a disturbed module.

Regulatory research on multi-unit monitoring highlights human-performance risks that become more pronounced as the number of supervised units increases. NUREG/CR-7126 describes issues such as change blindness and unit neglect, where attention drawn to one unit can reduce situation awareness (SA) for other units that appear normal [1].

This paper proposes a human-centered integrated overview screen for a four-module Large Display Panel (LDP). The goal is to provide an at-a-glance representation of module health, cross-module imbalance, and short-horizon trends on a shared display. The scope of this paper is limited to the integrated overview (center display), intentionally excluding module-specific detail pages.

2. Design Basis and Integrated Overview Concept

2.1 Operational Assumptions and Data Sources

A four-module configuration was assumed to represent a typical multi-module SMR control room scenario. Because plant-specific operational datasets for commercial SMRs are not available, process values and transient behavior were generated using the IAEA integral Pressurized Water Reactor (iPWR) simulator [2].

To reflect SMR-like signal organization on the overview, simulator variables were mapped to a representative Instrumentation and Control (I&C) hierarchy derived from the NuScale Final Safety Analysis Report (FSAR), Chapter 7 [3]. Signals related to protective functions were treated as Module Protection System (MPS)-type information, while routine control and balance-of-plant variables were treated as Plant Control System (PCS)-type information for display prioritization.

In addition, Post-Accident Monitoring (PAM) variables recommended by Regulatory Guide 1.97 were incorporated so that the overview retains essential safety-significant indicators during abnormal events [4].

2.2 Procedure-Based Task Analysis and Information Requirements

Operating procedures documented in the iPWR technical reference [2] were decomposed using a procedure-based task analysis template to identify information elements required for four-module supervisory monitoring. The analysis included representative normal evolutions (power and load maneuvers) and malfunctions/transients (e.g., steam generator tube rupture (SGTR) and station blackout (SBO)) and yielded 46 plant variables that were repeatedly referenced for monitoring, diagnosis, and decision-making in a multi-module context.

To keep the integrated overview cognitively manageable, the 46-variable set was reduced to a common plant indicator (total generator load) and nine key module parameters for side-by-side comparison: reactor power, neutron flux, pressurizer pressure, pressurizer level, containment (CBS) pressure, main steam system (MSS) header pressure, average temperature (Tavg), reactor coolant system (RCS) subcooling, and RCS flow. These ten items define the content of the integrated overview, while additional variables remain available through the on-screen detailed module data table and trend windows.

2.3 Integrated Overview Screen Design

The integrated overview was designed around the generator load and nine key parameters derived in Section 2.2, supporting perception, comprehension, and projection consistent with Endsley's three-level SA model [5] and aligned with HSI review guidance (NUREG-0700) [6]. Figure 1 illustrates representative disturbed and normal states of the center overview.

At the top of the screen, the total generator load is placed at the center as a common plant cue, while per-module alarm counts are displayed on the left and right. Modules are spatially encoded (left: Modules 1-2; right: Modules 3-4), enabling rapid module identification without serial label reading.

Below the top cues, a Key Parameter Matrix combines bar charts and radar charts. Bar charts are used for parameters with explicit reference limits or setpoints, supporting quick assessment against limit bands. Radar charts summarize coupled or context-dependent parameters, where geometric distortion provides a preattentive cue for cross-module imbalance and emerging deviations.

The visualization applies low-saturation tones as the default baseline and uses high-saturation highlights only when an anomaly is detected, so salience directly encodes abnormality. After localizing the affected module and variable via position, shape, and salience, operators can confirm exact values in the detailed module data table and review short trend windows at the bottom of the screen for anticipation. This layered, drill-down structure is intended to mitigate change blindness and unit neglect by supporting at-a-glance scanning while preserving access to detail.

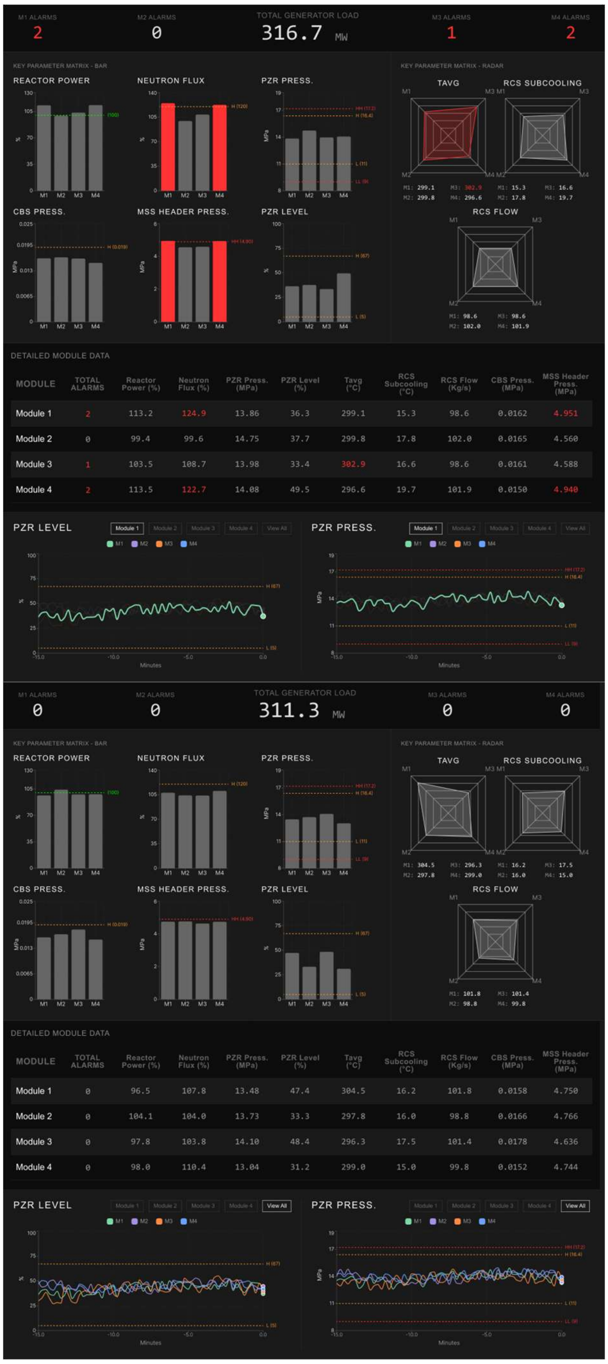

Fig. 1. Integrated four-module overview screen (center LDP) prototype: (a) abnormal condition example with selective high-saturation cueing; (b) normal condition example with low-saturation baseline.

3. Conclusions

This paper presented a human-centered design concept for the center integrated overview screen of a four-module SMR LDP. The proposed approach translates multi-unit monitoring concerns reported in NUREG/CR-7126 into concrete visualization and attention-management mechanisms, emphasizing cross-module comparison and pattern-based monitoring.

The current prototype is a concept-level implementation derived from simulator-based mapping and procedure analysis. Future work will integrate the overview into a high-fidelity Virtual SMR platform and experimentally evaluate its impact on workload, detection performance, and situation awareness under multi-module conditions.

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