

Migration to a Fully-Integrated Control Room

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ABSTRACT

The nuclear industry is faced with a pressing need to reduce operating costs in order to remain competitive with other forms of electric generation. While current industry initiatives are focused on incremental gains by streamlining work processes and reducing worker burdens, very few, if any, involve significant reductions in the base workload of a nuclear plant. Migration to a fully-integrated control room affords just such an opportunity.

This report describes an NPP digital instrumentation and control (I&C) system design, along with its corresponding human systems interface (HSI) design, which achieves high plant availability, while selectively applying digital equipment redundancy and integrating traditional I&C system partitions, to minimize the digital equipment needed, and thereby minimize initial installation costs and ongoing operations and maintenance (O&M) costs. An additional key component of digital equipment minimization is optimization of the digital interface to conventional plant sensors and controlled plant devices (e.g., pumps, valves), which requires no disturbance to plant cables and results in eliminating thousands of electro-mechanical relay control components.

The design is rooted in the highly integrated digital technology applied to the most recent advanced light water reactors under United States (U.S.) Nuclear Regulatory Commission (NRC) design certification review and approval. While this design employs technology from new plants, that technology has been adapted to the modernization of current operating NPPs. Hence, the highly integrated digital I&C and HSI design is referred to as the compact control room digital modernization (CDM).

Along with minimal digital equipment, the corresponding HSI design employs compact operator workstations with visual display units (VDU) and soft controls for both the main control room (MCR) and remote shutdown room (RSR), to immediately improve human performance and ultimately facilitate operating staff reduction. Some advanced light water reactors have demonstrated this staff reduction through full scope simulator testing of normal and abnormal plant conditions, with U.S. licensed operating crews from currently-operating U.S. plants.

Digital equipment minimization, compact operator workstations, and optimized plant component interfaces that require no disturbance to field cables, also facilitate implementation of the CDM over multiple phases, most of which

can be conducted during normal refueling shutdown windows. This phased implementation method includes a novel transition of the I&C, MCR and RSR with an operations centered focus.

This paper presents the CDM design, along with qualitative cost/benefit comparisons to currently operating plants with conventional analog I&C and HSI technology; this generation of I&C/HSI is referred to as a conventional control room (CCR). A CCR also includes NPPs that have been upgraded with digital systems, but retain the current partitions between plant I&C systems (i.e., no I&C integration) and retain the current plant system to control board configuration of current NPP control rooms. Even though these comparisons are qualitative, a compelling case is presented for the CDM.

Key Words: digital instrumentation and control, compact operator workstation, digital upgrade, digital modernization, operations and maintenance cost reduction

1 INTRODUCTION

This paper presents a novel approach to NPP HSI and I&C modernization that provides a migratory path for an existing CCR to a fully-integrated, all-digital control room, much like what is provided today for new plant designs. This migratory path is a logical extension of what some plants today are undertaking with digital upgrades of critical plant control systems, including improvements to the operator interface in the control room.

The digital modernization approach described in this report is referred to as the CDM. The scope of the CDM includes the plant I&C systems, the interface of those systems to plant instrumentation and controlled plant components, as well as the HSI for those systems in both the MCR and RSR. It is fully-integrated in the sense that all plant I&C signals are digitized and are therefore available to every monitoring and control function that needs them through various digital data communication interfaces. As such, all of the monitoring and control functions can be compacted into a workstation-based control room, and ongoing increases in component level, system level and plant level automation can be achieved cost effectively, to improve plant and human performance and ultimately facilitate operations staff reduction. This digital integration results in commensurate maintenance and plant support staff efficiencies.

In this paper the CDM is qualitatively compared to a CCR. A CCR is one that uses a number of main control boards as the operator interface for controlling the plant. These control boards host both discrete analog components and digital components. All operating nuclear plants today have some digital technologies, if nothing more than the plant computer. Those with more significant digital implementations are called hybrid control rooms, including ones where selected I&C systems have been upgraded one-for-one to digital systems, and for which the HSI has been upgraded to digital VDUs. But they are still CCRs in the sense that the monitoring and control devices, including the digital components, are distributed to specific locations on the control boards, which maintain a specific system-by-system orientation.

A CCR is characterized by: (1) Indications, controls, and alarms that are distributed to multiple control boards (CBs), each for a specific plant system(s). (2) This physical distribution requires an operator's physical transition from CB to CB; hence operation from a standing position. (3) Separate sit-down consoles provide access to the plant process computer and information technology system (ITS) functions. (4) I&C systems that are highly segmented with distinct functional and hardware partitions. A typical CCR is shown in Figure 1.

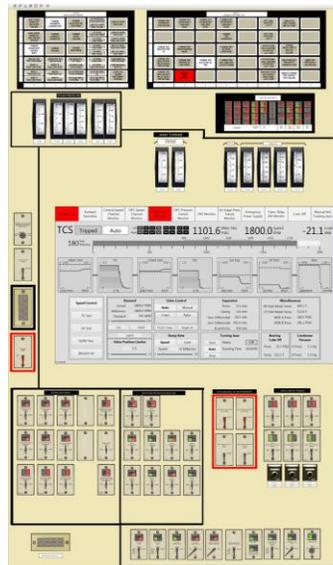
2 CONVENTIONAL CONTROL ROOM



Figure 1. Typical Nuclear CCR Today

The HSI for a CCR is mostly conventional analog indicators, controllers, alarm tiles, and switches. However, some CCRs have been upgraded (or are in the process of being upgraded) with digital systems. These digital upgrades typically retain the analog I&C system partitions of the original plant design. In addition, they most often retain the conventional analog HSI. But some replace these conventional HSI devices with modern VDUs, with the same system specific to VDU and panel distribution, as shown in Figure .

Some conventional HSI replaced by VDU, with same plant system to control board distribution.



Although the replaced system-specific HSI is improved by the VDU, the fundamental system to panel distribution characteristic of a CCR has not changed. Stand-up mobility is still required for monitoring and control.

Figure 2. Typical CCR with Upgraded Digital VDU Based his

A CCR can also be modernized in a phase-by-phase manner to take full advantage of digital technology, by maximizing the integration of plant I&C systems and employing advanced compact operator workstations. This type of modernization is referred to as the CDM, as shown in Figure 3.

3 COMPACT CONTROL ROOM



Access to all plant information and controls is provided from multiple compact operator workstations and plant overview display (POD).

Figure 3. CDM MCR End-point

The CDM is characterized by: (1) A POD that is the apex of the information hierarchy in the MCR. The POD continuously displays the status of all critical power and safety functions, and the plant systems used to control those functions. It also displays all plant alarms including those corresponding to the critical functions and systems. (2) Individual VDU-based workstations for each operator; in the CDM these are referred to as operator consoles (OCs). Each OC allows each operator to access all plant information and controls for all plant systems (safety and non-safety), and all plant process computer and ITS applications, through selectable graphic displays. (3) A very high level of I&C system integration, while maintaining sufficient segmentation to comply with safety criteria, including CCF that can result from shared hardware resources and common designs. (4) Maximum elimination of conventional circuits and relays, achieved through maximum use of software based implementations, minimum I/O interfaces to plant instrumentation and components, and maximum use of digital data communication. (5) Minimized I&C equipment to achieve low capital cost, low recurring O&M cost, installation in phased 30 day outages (one exception) with no changes to plant cabling. Redundancy is applied only for single failure criteria (SFC) compliance and to prevent single point vulnerabilities (SPV) that would lead to plant trip (i.e., there is no unnecessary equipment redundancy, because unnecessary redundancy reduces MTBF and increases all costs). (6) High plant availability through long MTBF, short mean-time-to-repair (MTTR), continuous self-testing of all digital components (minimal remaining manual tests are on-line) and ability to easily implement improved control/protection functions with no hardware mods.

The highly integrated CDM I&C architecture end-point is shown in Figure 4.

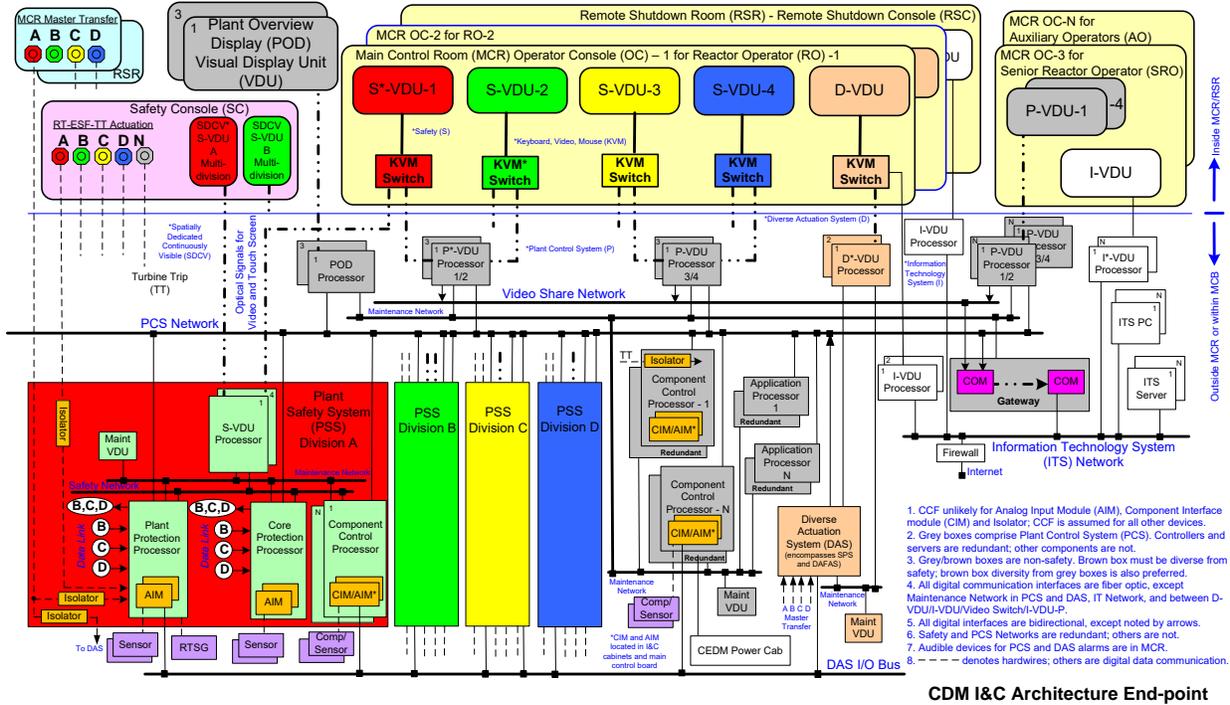


Figure 4. CDM I&C Architecture End-point

4 BENEFITS OF MIGRATION TO A FULLY-INTEGRATED CONTROL ROOM

One highly significant benefit of this approach is the elimination (in-place abandonment or removal) of large numbers of discrete electrical devices by converting much of the control logic to software while using existing plant wiring with no disturbance to the control room boundary. Figure 5 depicts this elimination for a typical motor-operated valve electrical wiring diagram (EWD).

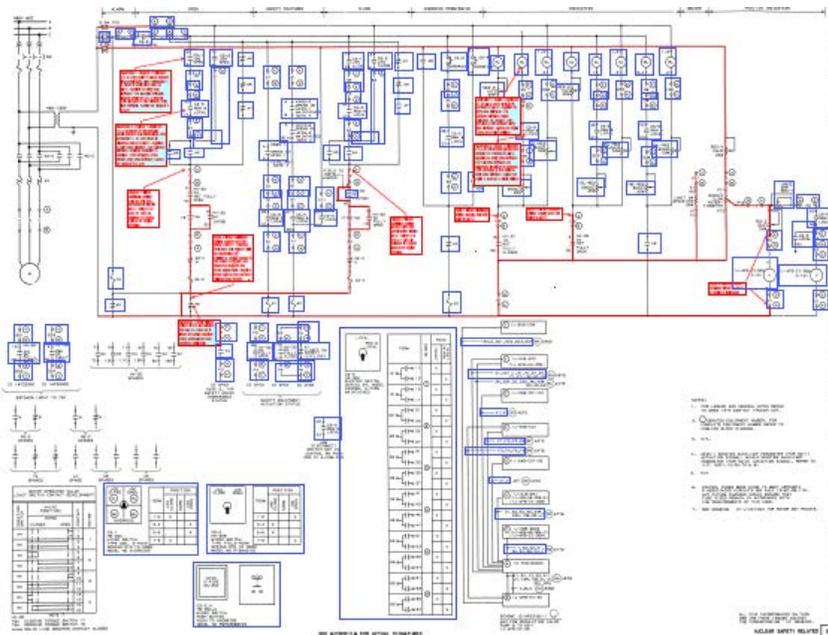


Figure 5. Typical Motor-Operated Valve EWD Showing Component/Wiring Elimination

Red-lines identify the circuits and components that must be retained for the CDM. The unmarked lines and blue boxes identify the components and wiring/cables that are no longer needed. For a typical MOV the eliminations are: 5 switches with 19 contacts, 4 relays with 19 contacts, 8 lamps with 9 resistors, 4 limit switch contacts, 1 fuse, 2 volt meters, 8 cables with 54 conductors.

The result is a significant reduction in the ongoing workload of maintaining, troubleshooting, testing, modifying, and securing spare parts for these electrical components. Moreover, it eliminates the chronic obsolescence and reliability problems that have proven to be so costly in maintaining these legacy analog components – costs that will increase exponentially if a second or even third round of life extension is pursued. Digital upgrades to the analog I&C systems can certainly resolve immediate analog obsolescence issues, and improve system performance and availability. However, converting legacy control systems to distributed control systems only eliminates the hardware resident in the former analog integrated control system. That does not address all of the interposing field devices (relays, timers, local panels, etc.) that exist in the electrical equipment rooms and out in the plant. These components are where the bulk of the maintenance and testing workload lies.

In addition, the CDM provides the basis for reductions in Technical Specification periodic surveillance test requirements and even reductions in credited minimum control room staffing. These benefits were approved by NRC for recent ALWRs, and were quantified for operating plant O&M staffing reductions in an Electric Power Research Institute (EPRI) Report 1011934, Task Evaluations for Nuclear Plant I&C Modernization Strategies [1]. In contrast to the CDM, upgrade of the operator interface in the control room under a hybrid control room concept provides only limited operating efficiencies and improved human factors. By retaining stand-up operations with main control boards, they cannot be as efficient as operating the plant exclusively from compact operator consoles. Similarly, while VDUs can improve the HSI for a specific plant system with conventional digital upgrades, the same physical plant system distribution of the CCR is maintained. Retaining the existing system partitions, which were necessary for analog technology, does not take advantage of the human performance improvements offered by compact operator workstations, and the resulting potential for O&M staff reduction.

For these reasons, considerably greater benefits are available in migrating from a CCR to a CDM. Future work in this project will address the quantification of these benefits for this particular case study.

5 MIGRATION PATH

While one-step implementation offers the potential for the lowest CDM implementation cost, it is commonly believed that the lost electrical generation revenue for an extended power outage makes the business case for a one step modernization approach unattractive. Therefore, the CDM has been optimized to facilitate the transition from a current CCR to the CDM in six phases that can be implemented during refueling outages.

However, before embarking on Phase 1, it is highly recommended to complete the CDM design for a specific plant to a level of detail that is comparable to that needed for a final safety analysis report (FSAR). This ensures that all components of the CDM are well understood, including how current plant systems will be integrated and the effect that has on the implementation phases. In general, knowing the end point ensures that each phase is synergistic with that end-point, to minimize unnecessary (and often very expensive) rework.

In addition, although the first three phases of this CDM implementation approach involve only non-safety systems and HSI, it is highly recommended that submittal of the CDM design and phased implementation approach be submitted for NRC approval as early in the project as practical. This would be conducted in parallel with non-safety systems migration (Phases 1 through 3). NRC approval would then be completed before safety systems migration (Phases 4 through 6).

This parallel NRC approval is recommended (but not required) to ensure licensing schedule/cost risk are managed early in the project. The licensing process would seek one-time approval of the CDM end point and phased implementation approach, along with NRC acceptance that each phase could be implemented under 10 CFR 50.59, “Changes, Tests and Experiments,” [2] with appropriate inspections.

While this is a novel approach to managing the risk of digital upgrades, it is consistent with NRC’s 2016 “Integrated Action Plan to Modernize Digital Instrumentation and Controls Regulatory Infrastructure.” [3]

In general, this novel phased modernization method is based on initially installing the key components of the CDM HSI, PODs and OCs, within the existing control room in Phase 1. These CDM components are initially used for monitoring only, getting their information for display from current plant digital systems, such as the plant computer. A typical current CCR is shown in Figure 6, and Phase 1 of the modernization transition is depicted in Figures 7 through 9.



Figure 6. Typical CCR Today



Figure 7. Phase 1- HSI Infrastructure (overhead perspective)



Figure 8. Phase 1- HSI Infrastructure (floor level perspective)

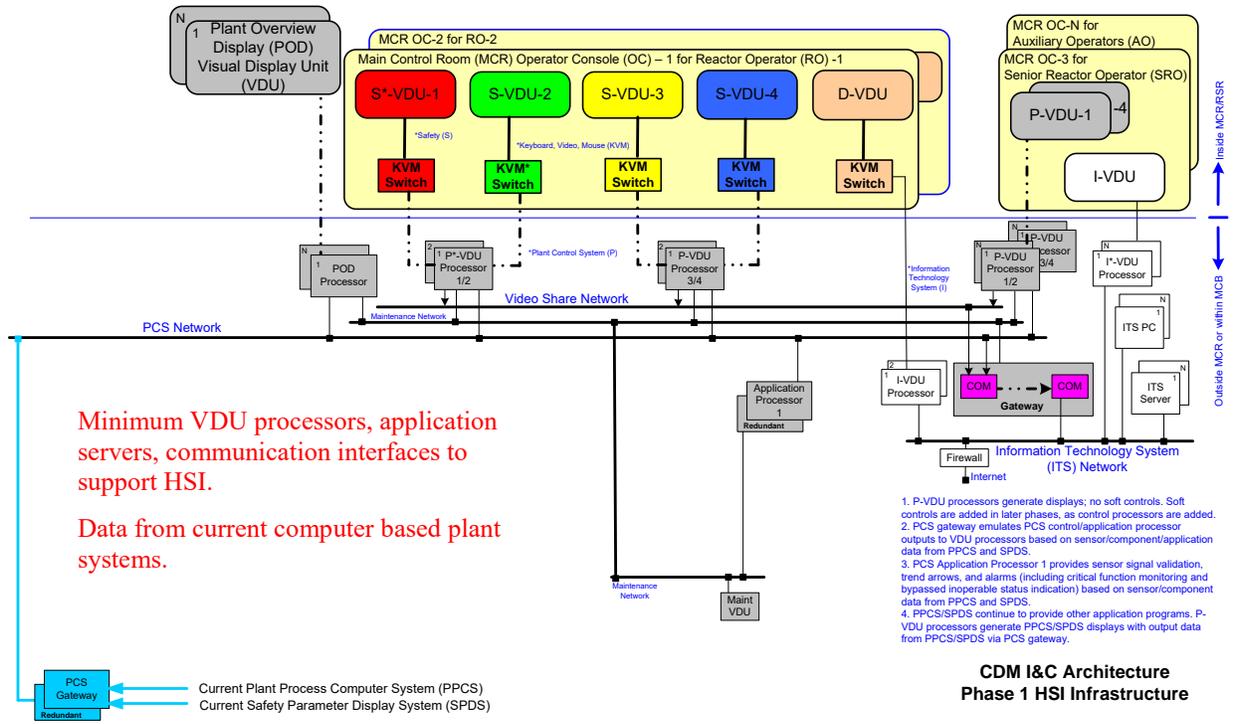


Figure 9. Phase 1- HSI Infrastructure I&C Architecture

Then in multiple subsequent phases, the current analog HSI is removed from the CBs in operationally logical groups, and the corresponding soft controls are activated on the OCs. This occurs concurrent with the installation of CDM control processors, and their direct interface to corresponding plant instrumentation and controlled components. This gradual migration, from conventional distributed HSI to modern compact workstations, is expected to ease operator training and reduce regulatory HFE transition concerns.



Non-safety HSI is transferred to OCs in logical operational phases.

Alarm tiles retained that support safety HSI.

Figure 10. Phase 3 – Non-safety Control. Completion of Non-safety HSI Migration (end-point of multiple sub phases)

The transition begins initially with non-safety HSI. The transition of all non-safety HSI is expected to require multiple sub phases due to limited outage durations. Where there is a tight operational integration between the safety HSI that remains on the CB and the removed non-safety HSI, a temporary non-safety VDU(s) is added to the CB. A typical migration of non-safety HSI/I&C at the end of multiple Phase 3 sub phases is shown in Figures 10 and 11.

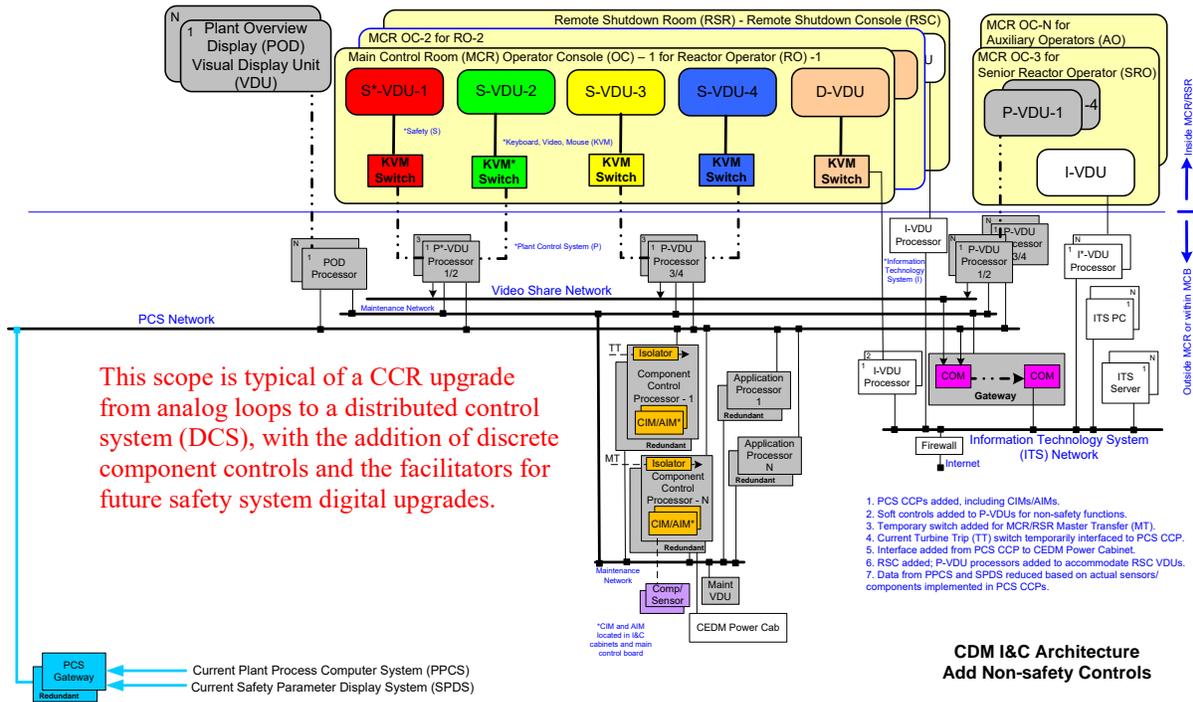


Figure 11. Phase 3 – Non-safety Control. Completion of Non-safety I&C Architecture (end-point of multiple sub phases)

A typical migration of the protection HSI/I&C infrastructure in Phase 4 is shown in Figures 12 and 13.

Safety HSI on plant protection CB is transferred to OCs and SC, except core protection HSI.



SC added to accommodate Class 1E SDCV requirements.

Figure 12. Phase 4 – Protection. One Phase to Add Plant Protection I&C/HSI Infrastructure

Add safety processors, I/O, communication interfaces. Add diverse processors, communication interfaces.

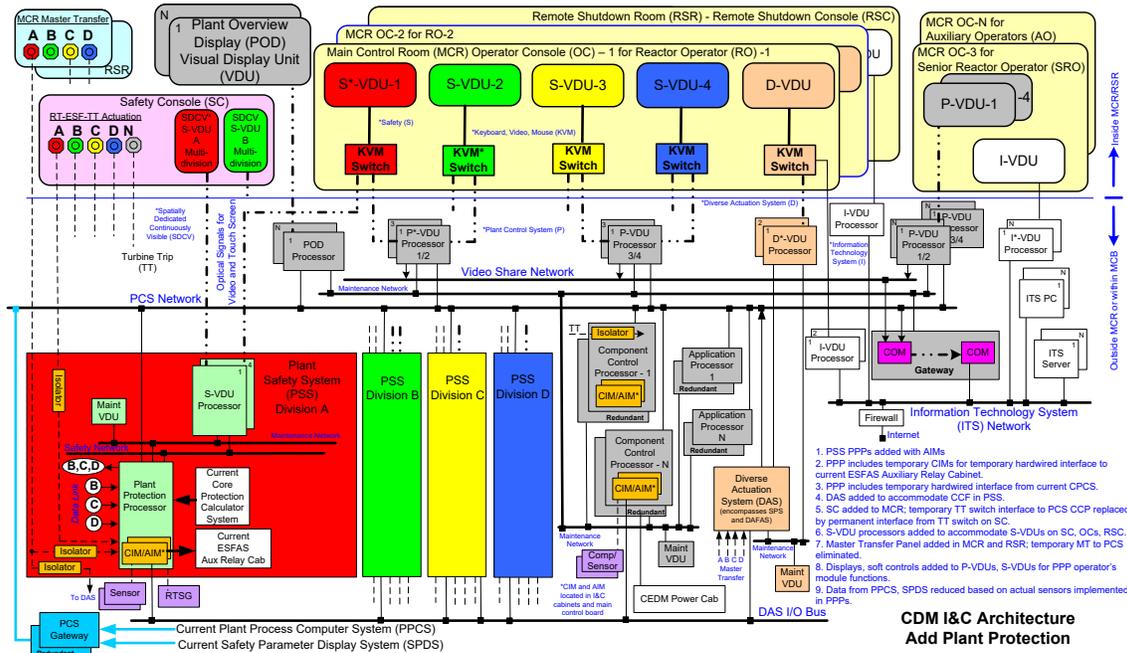


Figure 13. Phase 4 – Protection. One Phase to Add Plant Protection I&C/HSI Infrastructure

After the protection HSI/I&C infrastructure is in place, the conventional safety HSI can be migrated from the CBs to the OCs and SC, in multiple sub-phases in the same manner as the non-safety HSI was migrated previously. When safety HSI is transferred, any temporary VDUs that were added to the CBs in Phase 3 for non-safety HSI are also removed. The protection HSI/I&C infrastructure is also the foundation for the final migration of core protection functions, which completes the CDM implementation as shown in Figures 3 and 4, above.

The recommended phased implementation sequence is optimized, based on prerequisites that minimize temporary equipment and rework. Alternately, phases can overlap, and phases can be modified in scope/sequence to fit pressing plant needs, such as critical obsolescence or unreliability in current analog systems.

6 LICENSING CONSIDERATIONS

The CDM conforms to the essential safety criteria which have been identified by NRC in recent new plant reviews: redundancy, independence, diversity, determinism and simplicity. These safety criteria are embodied in the underlying basis of IEEE Std. 603, “IEEE Standard Criteria for Safety Systems for Nuclear Power Generating Stations.” [4] The key regulatory I&C focus for the CDM is expected to be CCF susceptibility and malfunction results analysis for both safety and non-safety systems, and communication independence and functional independence between divisions.

As for all plants the HFE regulatory focus will be on HFE implementation plans (IP) and results summary reports (RSR), in accordance with NUREG 0711 [5]. The one-time HFE approval would include a commitment for an HFE regression analysis for the previously completed HFE program elements, with a verification and validation (V&V) RSR, and design implementation (DI) RSR for each implementation phase. Integrated system validation, which is part of the V&V program element for each phase, would be

conducted with licensed operators using the plant's training simulator, as the simulator is upgraded for each implementation phase.

The CDM design presented here-in is viewed to be compliant with US NRC criteria, however, it has not undergone any NRC review. While most CDM features have direct correlations to I&C/HSI in recent plant designs that have received NRC approval, there are novel aspects of the CDM that have been included to improve its cost effectiveness and performance benefits. It is anticipated that the regulatory acceptability of the various design features of the CDM will be pursued in a future phase of this project.

7 CONCLUSIONS

The CDM is clearly a departure from digital upgrades methods presently being employed in the nuclear industry. But its potential for significant reductions in implementation costs compared to traditional methods and its potential for significant O&M benefits that cannot be realized with traditional methods, establish a compelling case for further development and evaluation.

8 ACKNOWLEDGMENTS

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