INTEGRATED CONTROL AND DIAGNOSTIC SYSTEM ARCHITECTURES FOR FUTURE INSTALLATIONS

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Nuclear reactors of the 21st century will employ increasing levels of automation and fault tolerance to increase availability, reduce accident risk, and lower operating costs. Key developments in control algorithms, fault diagnostics, fault tolerance, and distributed communications are needed to implement the fully automated plant. Equally challenging will be integrating developments in separate information and control fields into a cohesive system, which collectively achieves the overall goals of improved safety, reliability, maintainability, and cost-effectiveness. Under the Nuclear Energy Research Initiative (NERI), the U. S. Department of Energy is sponsoring a project to address some of the technical issues involved in meeting the long-range goal of 21st century reactor control system. This project involves researchers from Oak Ridge National Laboratory, University of Tennessee, and North Carolina State University. The research tasks under this project focus on some of the first level breakthroughs in control design, diagnostic techniques, and information system design that will provide a path to enable the design process to be automated in the future. This paper describes the conceptual development of an integrated nuclear plant control and information system architecture, which incorporates automated control system development that can be traced to a set of technical requirements. The expectation is that an integrated plant architecture with optimal control and efficient use of diagnostic information can reduce the potential for operational errors and minimize challenges to the plant safety systems.

Our initial research addressing the control and information system architecture for future nuclear installations involves the development of functional requirements. The plant architecture that we envision can serve to establish an integration platform for functional capabilities and a distributed communications framework to support operations, maintenance, and engineering personnel at a 21st century nuclear power plant. The distributed network can provide the backbone to convey information from the data acquisition sources to the users and applications that process the information. The issues of architecture being addressed in this research are:

1. Provide a common, consistent interface to I&C systems;
2. Enable uniform, transparent access to distributed data sources;
3. Establish a computing environment that facilitates the integration of information and applications (e.g., diagnostics and control);
4. Define a system architecture that permits flexibility in implementation and expandability of functional capabilities; and
5. Define an approach to application support that lays the foundation for standardizing functions and interface conventions for the nuclear power industry.

Simply establishing network links among the various systems and installing workstations as network nodes addresses only part of the desired support for plant personnel at the of 21st century plant. A key goal of this research is to provide common functionality throughout the control and information system architecture. In this way, the efficiency of plant personnel in performing their tasks can be enhanced and the possibility of user error while interacting with multiple systems and data sources can be reduced. The proposed architecture concept is based on a layered approach with the capabilities and services of the application environment supporting the functionality of applications (e.g., diagnostics or controls).

As part of the building blocks for this plant architecture, we are conducting research to develop methods for automated generation of control systems that can be traced directly to the design requirements. Our final goal is to allow the designer to specify only high-level requirements and a set of stress factors that the control system must be designed to handle (e.g., a set of prescribed transients, resistance to single failures…) To this end, the "control engine" automatically selects and validates control algorithms and parameters that are optimized to the current state of the plant, and that have been tested under the prescribed stress factors. The control engine then automatically generates the control software from validated algorithms. The basis of our proposed methodology is an iterative optimization process of control parameters and algorithms that is performed using a plant model. The plant model is kept current (e.g., updated with component failures or mode changes) by an on-line diagnostics system

As a proof of principle demonstration, we have implemented the automated control generation methodology using a standard off-the-shelf minimization algorithm. For this example, we have used a simplified steam generator model as plant model, and simple proportional or proportional-integral controllers. As design requirements, we selected the maximum 90% rise time for a step response and a maximum overshoot. The control engine immediately selected a proportional-integral controller with the optimized gain parameters that minimize the control actions while still satisfying the requirements.

Since our test model is non-linear, it comes as no surprise that the optimized gain parameters are a function of the operating conditions. This feature has been used to demonstrate the adaptive nature of our control-design methodology. By running the control-engine and the diagnostic system in parallel with the real system, we are able to input the current operating conditions and the status of the failed components. Thus, the control-engine determines on-line whether the original design requirements are met under the current operating conditions and plant state. If the design requirements are not met, alternate control algorithms or parameters that meet those requirements are calculated. The alternate algorithms can be implemented on-line as an integral part of the plant architecture.

In summary, the proposed plant architecture can provide the framework for the integration and use of plant controls, operator advisors, and diagnostic aids. Automated control design tools can provide a systematic approach, which uses system design requirements as its basis, to optimize control implementations at nuclear installations. The results of this approach for the 21st century plant can lead to improved performance, ameliorated availability, enhanced reliability, and, ultimately, increased plant safety.