



## **Development of the Advanced I&C in Nuclear Power Plants: ASICS and ADIOS**

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### **ABSTRACT**

Recently, digital technology is introduced to instrumentation and control systems in nuclear power plants. It is actively proceeded in the nuclear industry that the intelligent technologies apply to operation and operator support system. In this paper, The Automatic Startup Intelligent Control System (ASICS) that automatically controls the PWR plant from cold shutdown to 5% of reactor power and Alarm and Diagnosis-Integrated Operator Support System (ADIOS) that is integrated with alarms, process values, and diagnostic information to an expert system focused on alarm processing are described. The performance and the function of ASICS and ADIOS are evaluated with the real-time functional test facility and the results are shown that the developed systems are efficient and useful for operation and operator support.

### **INTRODUCTION**

Most operating Nuclear Power Plants (NPPs) have been installed with analog instrumentation and control (I&C) equipment which increasingly faced with frequent troubles, obsolescence, and high maintenance expenses. Digital technology, however, provides advantages, such as the ability to process large amounts of data, improved system reliability, the flexibility of adding new functions, automate periodic tests, self-diagnose component status, and capability of operation and maintenance using standardized components. Consequently, it is strongly recommended that nuclear industries adopt modern digital and computer technology to improve NPP safety, availability, and operating functions [1]. Operators control the plant manually according to the general operation procedures and technical specifications for startup operation of NPP. It increases operator's burden in startup operation. Therefore, an automatic control system is needed for the plant startup operation to reduce operator's burden [2].

Improvement in alarm processing and presentation in NPPs has been a great concern for years. Alarm information is the primary source to detect abnormalities in NPPs. The conventional hardwired alarm system, characterized by one sensor-one indicator, may lead the control room operators to be confused with avalanching alarms during plant transients [3].

## AUTOMATIC STARTUP INTELLIGENT CONTROL SYSTEM

The Automatic Startup Intelligent Control System (ASICS) automatically controls the PWR plant from cold shutdown to 5% of reactor power. The ASICS has a supervisor system and a distributed control system. The supervisor system has a supervisor program to control the distributed control system, and the knowledge base which has been designed from general operating procedures and the operator's experiences. The supervisor system is implemented using an intelligent real-time expert system shell G2. The distributed control system has four automation modes such as Heating I mode, Heating II mode, Critical mode and Secondary mode, and each mode has controllers and keep-up bands. The keep-up bands have a check-up function to start each automation mode or the function to hold on some process variables to allow for an operator's action. The ASICS functions are verified to receive control input signals from the Functional Test Facility (FTF) and send control results to FTF. Through this method, the developed control algorithm is evaluated in the real-time environment.

For the performance test of Mode I, the heat-up rate was set to 27°C/hr, the start temperature and the target temperature were 60°C and 176.6°C, respectively. The pressure set point was 24kg/cm<sup>2</sup>. From the Mode I test the heat-up time required to reach the target temperature was 7 hours. The automatic temperature controller saved about 2 hours in heat-up time as compared to the manual operation for heat-up. The measured heat-up slope was uniform and the pressure was controlled constantly. Figure 1 shows an operation display of the supervisory control system on the Mode I operation. During this operation operator can watch the status of ESF & RESET switches, control signals and permissive signals. By the Mode I automatic operation procedures the Mode I operation procedures are displayed in this display also. Some operation procedures are displayed after the results of automatic actions and the others are displayed to give operator information what next operations one should do. Figure 2 shows the overall plant parameters display of the distributed control system. In this display the status of important components and plant parameters are displayed. If operator want to check the detailed parameters and trends of parameters one can use the touch screen to display his concerns using a simple method touching the block name on the screen. For the operation test of Mode II the heat-up rate was the same as in Mode I, the target temperature was 292°C. The pressure set point was 157kg/cm<sup>2</sup>. From the Mode II test the heat-up time required to reach the target temperature was 8 hours. The automatic temperature controller saved about 3 hours in heat-up time when compared to the manual operation. The measured Pressure-Temperature (P-T) curve was located in the required operation boundary. From these tests we could confirm the supervisory control rules and the controllers of the distributed control system were designed well, as expected. ASICS could save about 4 hours in heat-up time and could reduce the chance of repeated operations and trips. ASICS could also reduce the operator's burden [4].

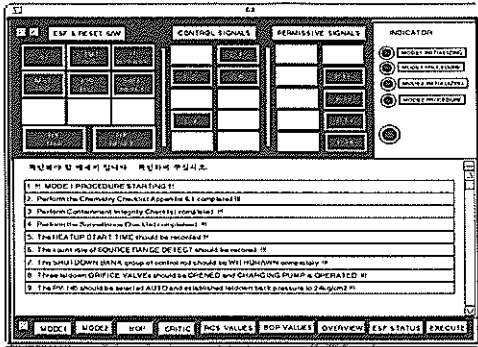


Figure 1. An Operation Display of the Supervisory Control System.

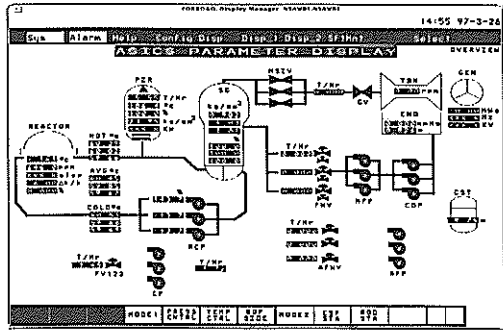


Figure 2. Overall Plant Parameters Display of the Distributed Control System.

## ALARM AND DIAGNOSIS-INTEGRATED OPERATOR SUPPORT SYSTEM

The overall objective of Alarm and Diagnosis-Integrated Operator Support System (ADIOS) is to improve the operation performance of the man-machine interface system by integrating alarms, process values, and diagnostic information to an expert system focused on alarm processing. The ADIOS was implemented using the G2 real-time expert system shell. Its knowledge base is constructed on the basis of the process knowledge of a Korean nuclear power plant and using some advanced alarm processing concepts. Every alarm is treated as an object of alarm class which is classified into three major categories; 1) process alarms, 2) equipment alarms, and 3) plant alarms. Objects consist of various attributes including tile message, process value, alarm firing set-point, activation status, priority, acknowledgement or reset status, causal alarm, level precursor, and so on. Therefore each alarm object with those attributes contains all necessary information for processing and displaying itself in the system. Some of attributes of an alarm object changes their values dynamically during a run of ADIOS. The values of process variable and status are fed into the attribute, "process value," of the corresponding alarm objects. "Acknowledgement or reset status" is used to control the flashing display depending on the acknowledgement status of the alarm when it is activated or deactivated. The attributes, "casual alarm" and "level precursor" are used for prioritizing the alarm on the basis of the relationship with other alarms. The alarms in ADIOS initially had their own default priorities which are then changed according to plant-mode dependency, equipment-status dependency, multi-setpoint relationship, or some other method. The dynamic prioritization is determined by using "Rules" and "Procedures" of the expert system shell. The plant-mode dependency is a method that the alarms activated as a consequence of the plant mode change are de-prioritized from the default priority. Multiple set-point relationship uses the relationships among several alarms on the same process parameter. For example, when both the low and low-low level alarms of a steam generator are activated, the priority of the low alarm should be lowered. The activated alarms are

displayed as rectangles around the process value on the process overview mimic and chronological alarm lists with different colors in accordance with their priorities [3,5].

The diagnostic function module will be incorporated into ADIOS to estimate and inform the root causes of some complicated failure behaviors for operators. Because, compared to the alarm systems, operator diagnostic systems directly manipulate process parameters and variables in addition to alarm signals, more detailed analysis such as diagnosis of the causal alarm, defect of components and process abnormalities can be made by these diagnostic systems. All alarms represented process disturbance may occur as a result of sensor failures or hardware failures. ADIOS provides operator the causal alarms to diagnose sensor failures or hardware failures as manipulating process parameters and variables. To verify only the functional effectiveness of the developed alarm and diagnosis system without investigation of operational performance, it was tested and operated with the test scenarios generated in the real-time test facility by activating malfunctions to simulate abnormal plant conditions. Figure 3 shows the processing flow for alarm, diagnosis and display in ADIOS. Figure 4 shows the primary overview schematic display which demonstrated TMI-II accident.

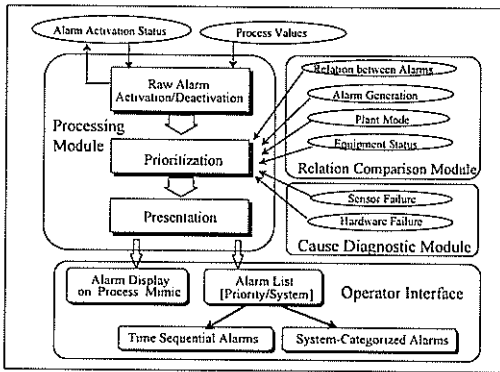


Figure 3. Processing Flow for Alarm, Diagnosis and Display.

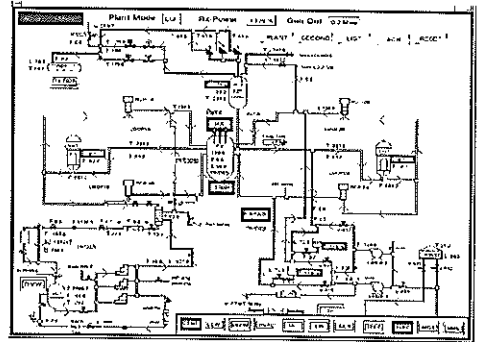


Figure 4. Primary Overview Schematic Display.

## FUNCTIONAL TEST FACILITY

In applying the digital technology to nuclear power plants, we should ensure that it does not endanger the safety and reliability of the plant. Testing and validation of the function and performance of a digital system should be done in a realistic environment prior to its installation in an NPP. The objective of instrumentation and control FTF is to test and validate newly developed digital control and protection algorithm, alarm reduction algorithm, and the performance of operator support system, etc. The FTF provides a simulated testing environment as an experimental test bed. The FTF software consists of a mathematical model which simulates a three loop, 993 MWe pressurized water reactor, and a supervisory program that comprises all the instructions necessary to run the FTF. The hardware equipment

provides an interface between host computer and simple test panel or developed target systems to be tested. The interface module can provide Ethernet or VXI interface to developed prototype using shared memory and also provide the display page for the value of simulated variables [1,6,7]. Graphic user interface supports an easy and friendly interface between FTF and users. It is implemented through a Picasso-3 graphic tool developed by the Halden Reactor Project. The FTF is applied to an ASICS and ADIOS as shown in Figure 5 to test its algorithm and performance. The results of the test show good operational performance of the FTF in normal and transient conditions.

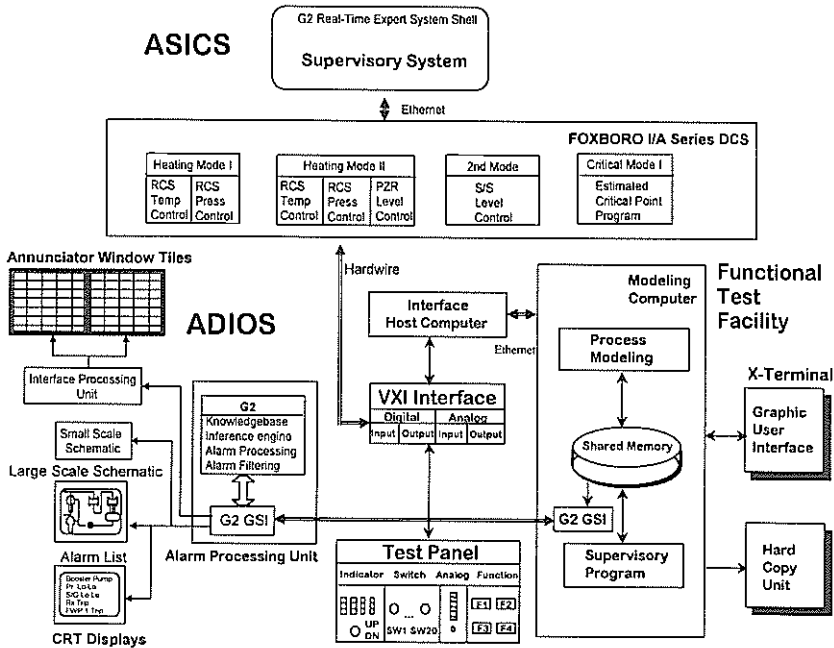


Figure 5. ASICS and ADIOS with Functional Test Facility.

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### REFERENCES

- [1] Kwon, K. C., et al., "The Real-Time Functional Test Facility for Advanced Instrumentation and Control in Nuclear Power Plants," IEEE Transactions on Nuclear Science, Vol. 46, No. 2, April 1999.

- [2] Jung, C. H., et al., "Development of Automatic Start-up Intelligent Control System for PWR Plant," *Cognitive Systems Engineering in Process Control*, pp. 51-56, Kyoto, Japan, Nov. 12-15, 1996.
- [3] Lee, D. Y., et al., "An Implementation of Alarm and Diagnosis-Integrated Operator Support System," *Cognitive Systems Engineering in Process Control*, pp. 63-70, Kyoto, Japan, Nov. 12-15, 1996.
- [4] Inazumi, Y., and Takashima, M., "Automatic System for Plant Heatup and Cooldown Operations in Japanese PWR Plants," *International Symposium of NPP I&C*, pp. 2-15, Tokyo, 1992.
- [5] Kim, I. S., "Computerized System for On-line management of Failures: A State-of-Art Discussion of Alarm Systems and Diagnostic Systems Applied in the Nuclear Industry," *Reliability Engineering and System Safety*, Vol. 44, 1994, pp. 279-295.
- [6] Edwards, R. M., Lee, K. Y., and Hughes, Daniel E., "Testbed for Nuclear Plant Instrumentation and Control Validation," *Proceedings of the 1996 American Nuclear Society International Topical Meeting on Nuclear Plant Instrumentation, Control and Human Machine Interface Technologies*, pp. 287-294, University Park, PA, USA, May 6-9, 1996.
- [7] Garcia, Humberto E., Vilim, Richard B., and Dean, Eric M., "Hierarchical Control of Reactor Inlet Temperature in Pool-Type Plants – II : Implementation and Results," *Nuclear Science and Engineering*, Vol.125, Mar. 1997, pp. 337-347.