A NUCLEAR SIMULATOR CONCEPT FOR HARDWARE-IN-THE-LOOP DEVELOPMENT OF DIGITAL FEEDWATER CONTROL SYSTEM

by

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April 1990

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ABSTRACT

The level control characteristics of **recirculation-type steam generators (RSGs)** and **boiling water reactors (BWRs)** are complex enough to justify the use of real-time simulation in conjunction with control system hardware to minimize the control development effort and significantly reduce the control system startup time. This paper describes a **personal computer (PC)**-based nuclear simulator concept for **hardware-in-the-loop (HIL)** development and testing of **digital feedwater control systems (DFCSs).**

The concept consists of a PC connected with a digital control system via a communication module or actual **input/output (I/O)** hardware. The PC contains the real-time simulation software of a PWR or a BWR including the associated **feedwater (FW)** train and steam side components. The simulation software is developed by interconnecting modules of PWR/BWR, pressurizer, RSG, pipe, pump, and valve available in the **Modular Modeling System (MMS)**. The simulation incorporates interaction from a graphic front end, linear analysis (e.g., eigenvalues and zeroes), and convenient user interface for debugging.

To demonstrate this concept, the conventional DFCS was implemented in Bailey Network90 system and was linked with a MMS/PC model of a RSG and FW train by a RS-232C serial cable.

The simulator can be used for various phases of a DFCS project such as evaluating alternative control concepts or improving the existing control strategy, and familiarizing operators/control engineers with the control system. The simulator can also be used for other applications such as developing a digital control system for BWR recirculation flow, digital protection and diagnostic systems, and digital fossil power plant control systems.

INTRODUCTION

With the obsolescence of analog control hardware and scarcity of analog spare parts, controlling the downcomer water level of a RSG or a BWR by a DFCS is gaining increased acceptance and implementation by the utility industry[1]. The advantages over the conventional analog control include:

- Increased hardware reliability, particularly through redundancy.
- Reduced cost and space.
- Increased flexibility to reconfigure.
- Easier use of advanced control algorithms.
- Elimination of the need for periodic hardware calibration.

While there is little doubt that DFCS is the way to go, how can one **effectively** undertake and complete a DFCS project? Any digital or **analog** system project is subject to human error and unforeseen problems. However **unlike the analog technology**, the digital technology as applied in the proposed concept lends itself to minimizing their impact. Some of the potential problems are discussed in the next paragraph.

The hardware and software specifications may need several iterations that affect project cost and schedule. The selected hardware may not be as rugged, fault-tolerant, human-engineered, and well documented as initially believed. The software may not be as user-friendly as originally expected. If the DFCS algorithms are developed by one-for-one replacement of existing analog algorithms, the coding may have errors. If new and improved algorithms (e.g., level control at low power) are used, there may be errors and unsatisfactory gain settings that will be identified during field startup. While it is generally easy to incorporate changes in digital systems based on operator feedback, the impact on project cost and schedule may be adverse if changes are done in the field. There may be errors in field I/O changes.

All of the above problems except errors in field I/O changes can be **avoided** by the HIL simulation concept described in this paper (see **Figure 1**), leaving only the field I/O changes to be debugged in the field. The proposed simulator will therefore produce a **significant** reduction in the cost, schedule, and risks associated with a DFCS project.

As shown in Figure 1, the plant process dynamics is modeled in a PC that interacts with a digital control hardware/software system either through a communication link over a serial or parallel data highway or through actual I/O hardware. A validated first-principles

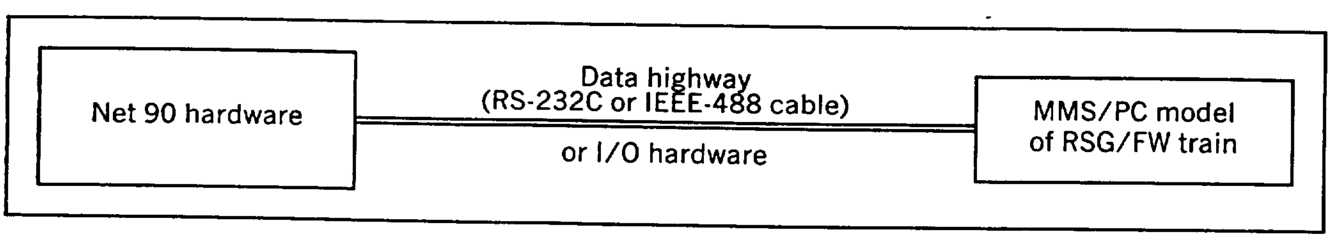

Figure 1--Nuclear simulator concept for hardware-in-the-loop development of DFCS.

model of the process is desirable, particularly if new control algorithms and operator interface are to be developed. With today's automated modeling tools such as MMS[2]--MMS is commercially available--the schedule and cost of developing such a model are insignificant compared with the scope of DFCS project. At the same time, the return on such an investment in terms of minimization of project cost and schedule is substantial.

CONCEPT

The PC contains the real-time simulation software of a PWR or a BWR and associated FW train and steam side. The digital control system contains the software for FW control algorithms. The communication module or the I/O hardware carries the simulated process information (e.g., level, flows, pressure, temperature, and power) from the PC to the control system and the control commands (e.g., valve positions and pump speeds) from the control system to the PC.

The simulation software is developed by graphically interconnecting generic modules of PWR/BWR, RSG, pipe, pump, and valve available in the MMS library to represent a particular plant arrangement and then customizing the modules to that plant by defining the values of parameters based on physical and operating data from the plant data base. The simulation includes the capabilities of interactive simulation control, linear analysis (e.g., eigenvalues and zeroes of the simulated plant), and monitoring the internal variables of the process model for debugging. A graphic front end featuring plant schematic and trends of selected variables can be included for real-time simulation monitoring and control. Like the plant model, the control software is also configured graphically from function blocks off-line using the PC as an **engineering work station (EWS)** and then down-loaded into the control hardware. The configuration can be finetuned directly into the control hardware.

CONCEPT DEMO

The feasibility of the concept has been established using the Bailey Network90 system[3], which included a **Multi-Function Controller (MFC)** module and a **Communication Interface Unit (CIU)** module, and the PC model of a typical RSG with its FW train and steam lines. **Figure 2** shows a schematic of the demonstration system. The conventional one-element and three-element feedwater control logic for modulating the FW bypass and main regulating valves, and the conventional control logic for

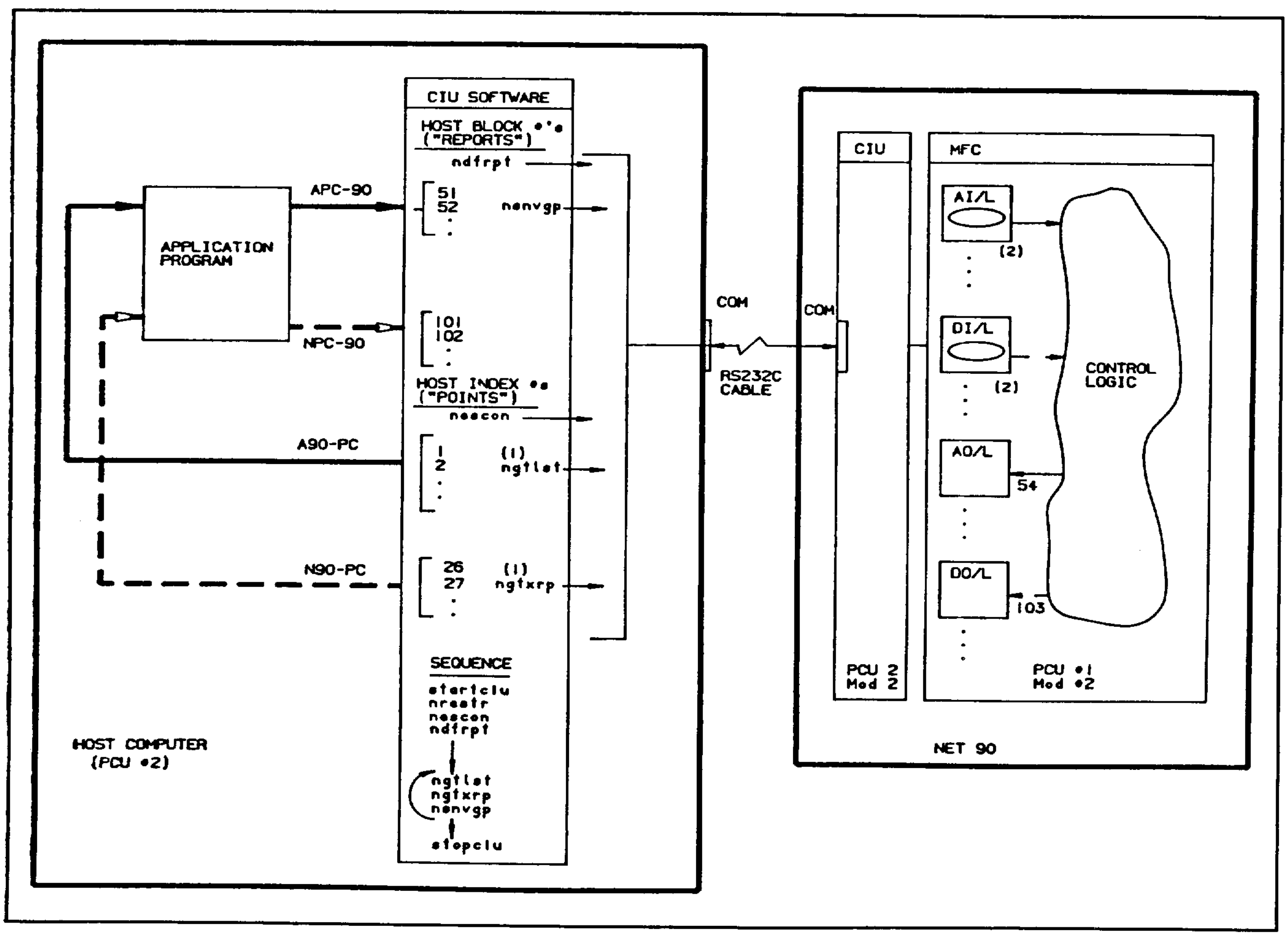

Figure 2--Schematic of the concept demonstration.

modulating the FW pumps and steam throttle valve were configured on a PC-based Bailey EWS and then downloaded into the MFC. The PC simulation model was developed from a previously developed MMS model[4] and a CIU driver subroutine. The measurements from the simulated plant to Network90 include narrow and wide range levels, FW and steam flows, FW and steam header pressures, FW temperature, power, and FW pump status.

The signals from Network90 to the simulated plant include demands for FW regulating valve positions, pump speeds, and steam throttle valve position. The Network90 control logic can be monitored and tuned from the **Configuration and Tuning Module (CTM)** in the Network90 cabinet, one function block at a time, or from the Bailey EWS connected to the Network90 through a **Serial Port Module (SPM)**.

Figure 3 shows the hardware setup used for demonstrating the concept. The Network90 hardware is located in the middle cabinet. The PC on the left is connected with the CIU module in the cabinet by a serial cable and runs the plant model, while the PC on the right is connected to the SPM by a serial cable and runs the Bailey EWS in CAD mode under monitor/tune option. Using the keyboard of the simulation PC, the simulation can be run in the MMS linear analysis mode, or the graphical simulation mode without Network90, or the HIL mode with Network90. Plant equipment malfunctions such as FW pump trip can also be introduced from the model PC. The outputs of Network90 function blocks are updated on the screen of the EWS. Also the tunable specifications of the function blocks can be changed from the EWS. **Figure 4** shows a closeup of the plant simulation PC and Network90, while **Figure 5** shows the graphic front end of the plant simulation.

The demo is started from some steady-state **initial condition (IC)**. Once the communication link functioning is established, the simulation is synchronized with the control system using a IC/hold/run switch. Normal operation of the simulated plant can then be performed from the Network90, while equipment malfunctions such as a FW pump trip can be initiated from the simulation control. The simulation runs in real time on a 386 PC between 2% and 100% power.

CONCLUSIONS

A DFCS project represents an excellent opportunity to upgrade the performance of a power plant. The use of the simulator concept demonstrated in this paper for HIL development of the DFCS can significantly contribute to the success of the project. Further the foregoing concept is generic in that it can be used on projects involving development, maintenance, upgrading, and evaluation of digital control, protection, and diagnostic systems.

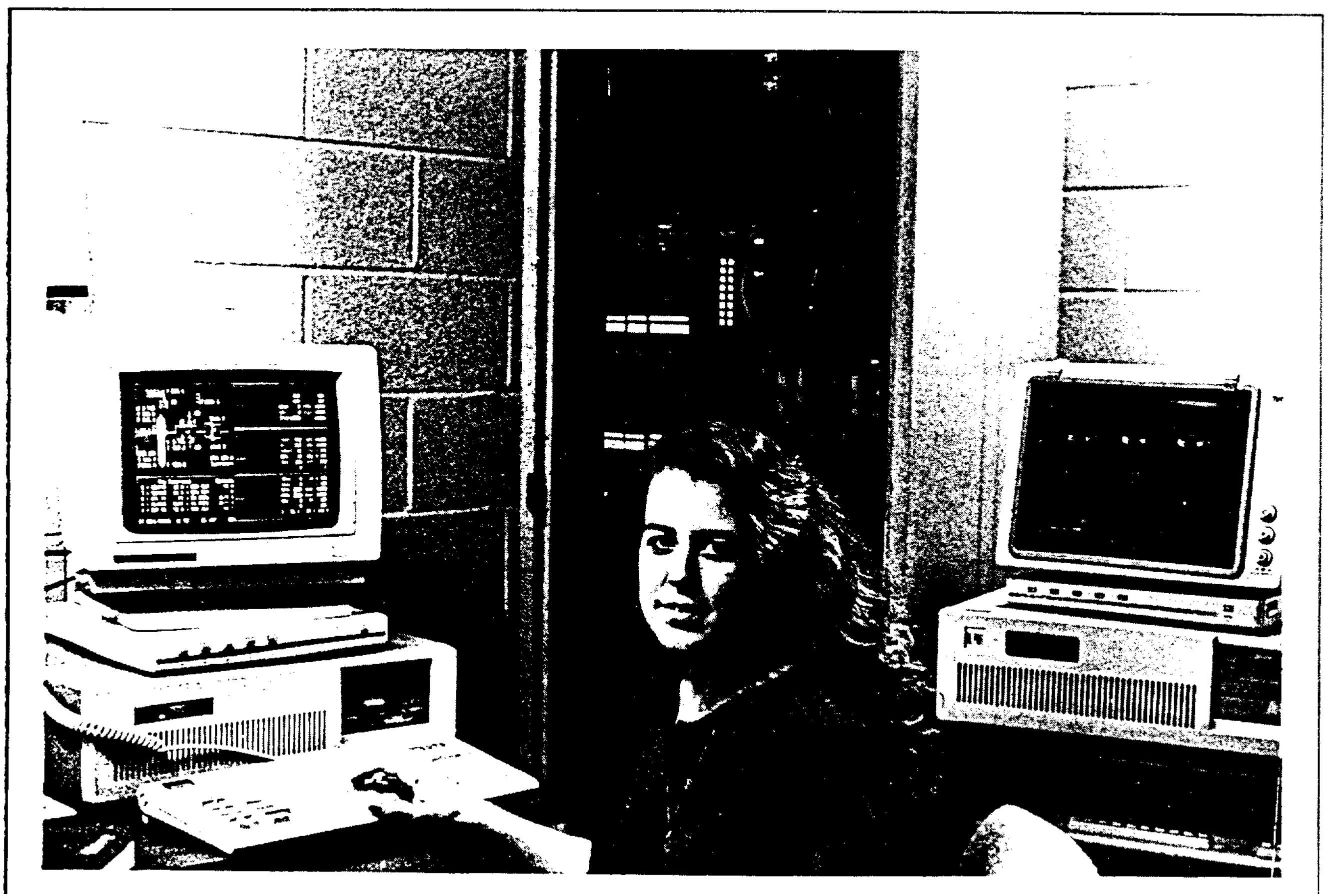

Figure 3--Hardware setup for the concept demonstration.

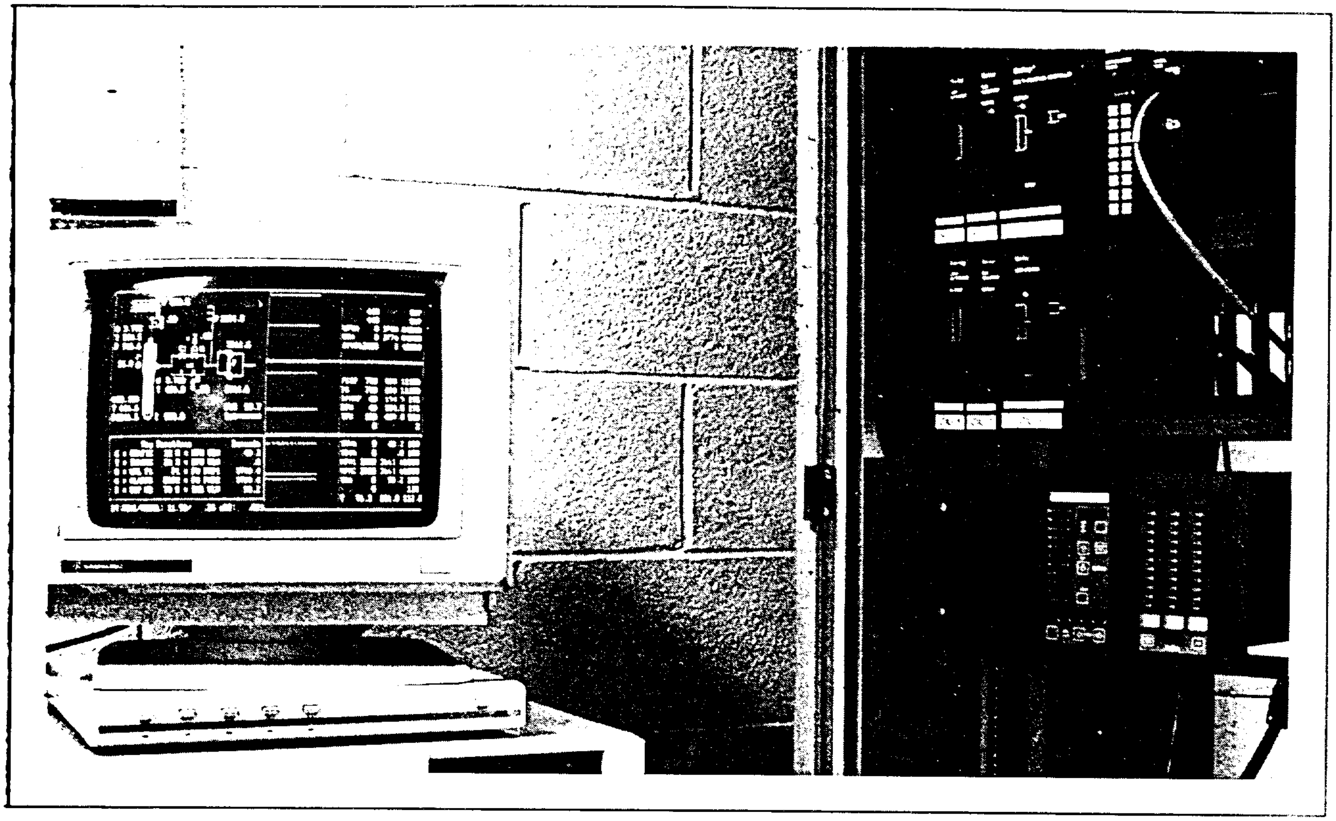

Figure 4--Closeup of the Model PC and Network90.

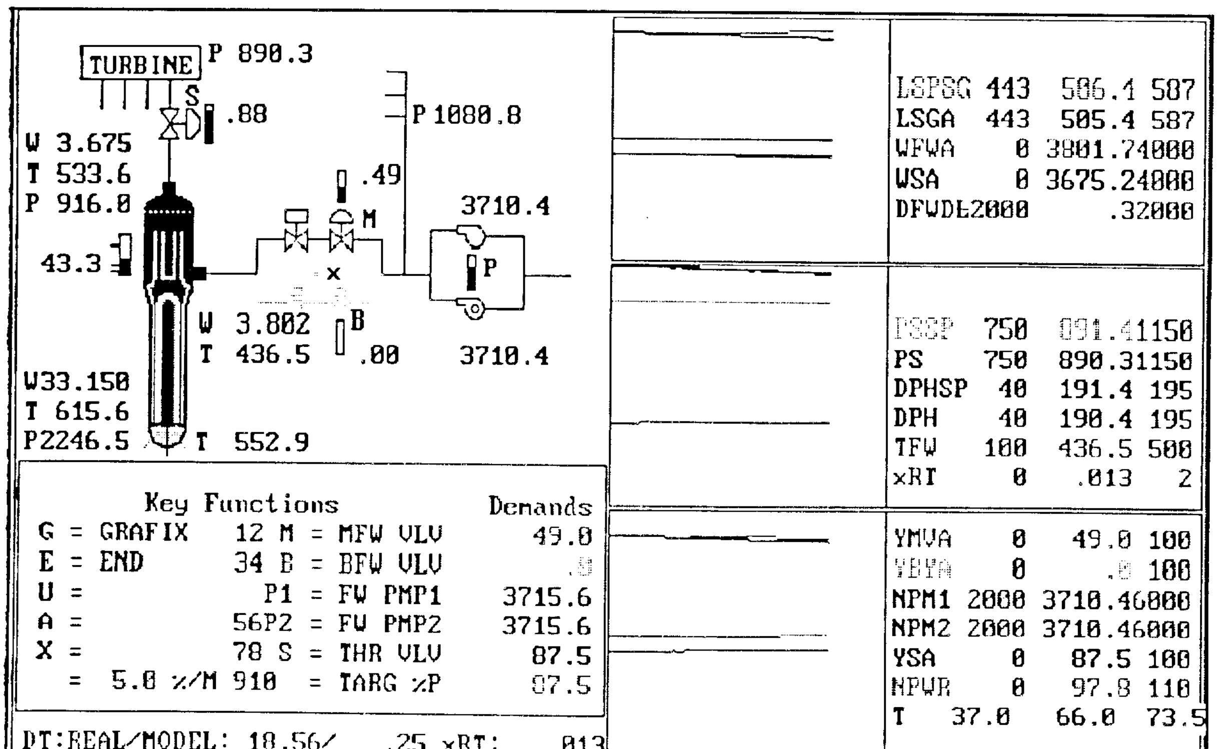

Figure 5--Graphic front end of plant simulation.

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