DCS EMULATOR DEVELOPMENT FOR NUCLEAR POWER PLANTS

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Abstract

Continual training of operators is one of the principal means by which Nuclear Power Plant (NPP) operational efficiency can be improved. Since this training cannot take place in the actual NPP, NPP simulator applications must be used instead. While digitalization scope of Instrumentation and Control (I&C) systems has been expanded to the entire plant by using Distributed Control System (DCS) implementation, Hitachi has implemented DCS emulator on a general purpose Personal Computer (PC) and applied it to simulator applications. This paper reviews such DCS emulator development for NPP by Hitachi.

1. Introduction

Since the 1980s in Japan, Hitachi, Ltd. has developed, built, supplied and maintained entire NPPs including complete I&C systems based on the HIACS (Hitachi Integrated Autonomic Control System) industrial distributed controller (an in-house developed DCS platform). Hitachi has also developed, built, supplied and maintained Operator Training Simulators (OTS) that simulate regular as well as start-up, shut-down and transient plant conditions to help NPP owners and operators realize safe and efficient operation. To support its OTS, Hitachi has developed and improved plant Models and I&C models to make its simulators behave as much possible like a real NPP. The core of Hitachi's latest I&C models are its DCS emulators. Using a DCS emulator to help model I&C simulators is the most effective method to date because DCS emulators can directly execute the actual DCS application software used in the I&C systems of a real NPP.

This paper focuses on this crucial technology by describing Hitachi's current DCS platform emulator (for the HIACS-7000) and reviews the highlights of the next generation DCS emulator which Hitachi is developing for its latest DCS platform G-HIACS NuSAFE. Hitachi believes that by applying this new generation of DCS and DCS emulator, Hitachi can supply state-of-the-art I&C systems for coming new-build NPPs (e.g. ACR-1000, U-ABWR) and NPP full scope simulators.

2. Hitachi's DCS and NPP simulator development experience

Error! Reference source not found. summarizes the evolution, through 3 generations, of Hitachi DCS and simulators since development first started in the 1980s.

The 1st generation simulator systems were constructed using multiple computers to share the system load. The target plant type was the first generation of Japanese Boiling Water Reactors (BWRs). The target plant control systems were composed of control modules and analog

equipment. The simulator I&C model was a simple mathematical/Boolean logic reproduction (running on the computers mentioned above) of the electrical interlock circuits.

The 2nd generation simulator systems were constructed using computers and work stations. The target plant type was still Japanese BWRs. The target plant control systems were by this time made up of both digital controllers (about half) and traditional analog equipment. So the control system models in this generation of simulator were an emulation of the digital controllers and the electric interlock model (resident in the computers).

The current (3rd) generation simulator systems are implemented entirely using PCs. The target plant types are refurbished BWRs and Advanced BWRs (ABWRs) with control systems that are entirely DCS-based. In this generation, the simulator control system models are built around DCS emulators.

Table 1 The evolution of Hitachi NPP simulators

Phase of Progress	1st Generation (1980s~)	2nd Generation (1990s~)	Current Generation (2000s~)
Simulator System	Control Computers	Control Computers Work Stations	General-purpose PCs
Target Plant Type	BWR		Refurbished BWR, ABWR
Target Plant Control Systems	Control modules Analog equipment	Digital controller Analog equipment	Integrated digital system (DCS)
Simulator I&C Models	Replicated interlock model	Emulation of digital controller + Interlock model	DCS Emulator

3. Relationship between ABWR training simulators and DCS emulators

This section describes Hitachi's latest ABWR training simulator and DCS emulator. Figure 1 shows Hitachi's latest full scope ABWR training simulator system architecture consisting of the following sub-systems:

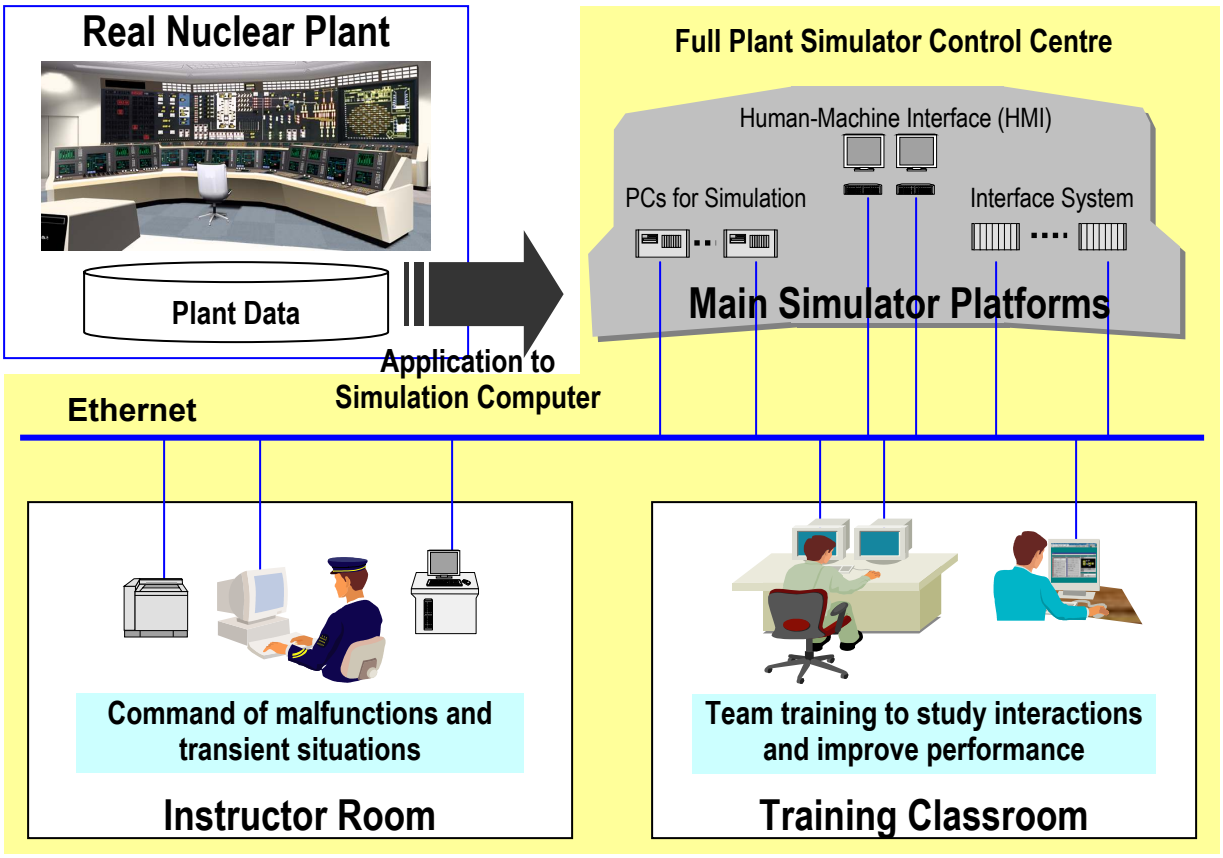

Figure 1 Overview of the latest full scope ABWR training simulator configuration

1. PCs for simulation

The Simulation Computer consists of standard PCs on which NPP behavior and DCS processing are simulated. The ABWR Simulation Computer architecture is shown in Process Computer System

The Process Computer System (PCS) used in the Simulator Computer architecture is identical to the actual NPP PCS. The PCS provides key functions to operate an NPP, for example, automatic operation, plant status calculation and summary status monitor.

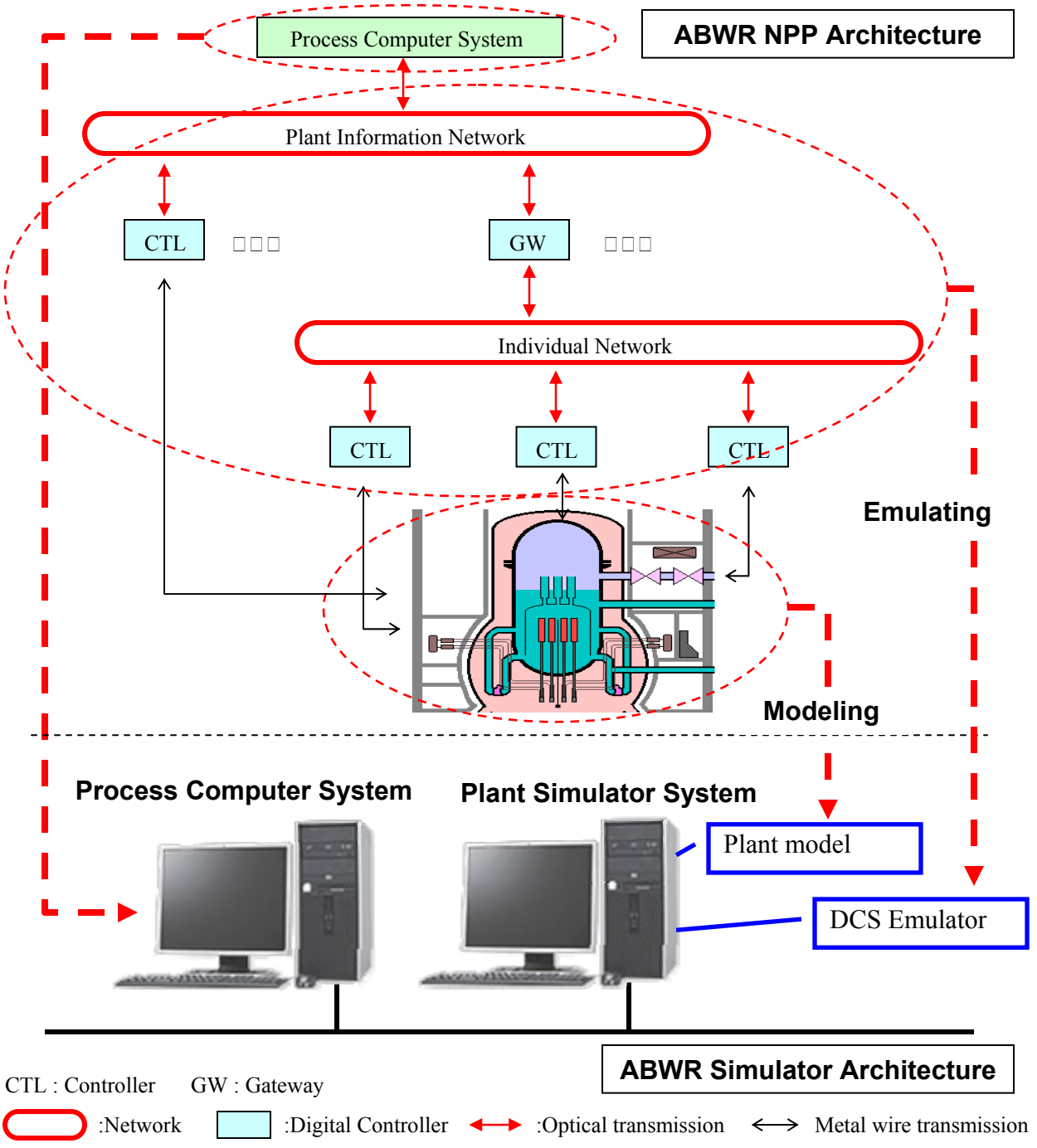

Figure 2 - Architecture of the ABWR PC for simulation computer

b) Plant simulator system

The plant simulator system is composed of the plant model and the DCS emulator working together and running on a standard PC.

- Plant model

The modeled real plant behaviour runs on the plant simulator system. The plant model is written in a high-level computer language such as FORTRAN.

- DCS emulator

The advantage of the latest generation DCS emulators lies in their ability to run actual compiled versions of the DCS application software. In the case of Hitachi's current generation ABWR simulator, over 60 HIACS-7000 controllers can be emulated on a single emulator.

2. Human machine interface (HMI)

The HMI used in the simulator is identical to the actual NPP HMI.

3. Interface system

The Interface System is a group of DCS controllers that receive plant status data from the plant simulator system for simulation and display on the operators display Panels; they also transfer operator action data back to the plant simulator system.

4. Instructor room

Through the instructor console, instructors can construct and control training scenarios as well as inject malfunctions and transient situations into the plant model.

5. Training classroom

The training classroom, equipped with a main control panel and a wide display panel, mimics a real NPP control room thus providing a realistic environment for operator training.

4. Overview of HIACS-7000 series DCS emulator development

This section presents an overview of the HIACS-7000 series DCS emulator. The HIACS-7000 series DCS emulator is an existing product being applied to the latest ABWR training simulator (see section 2).

4.1 HIACS-7000 series DCS emulator concept

The HIACS-7000 series DCS emulator concepts are applied to the ABWR training simulator and designed for the Verification and Validation (V&V) process of the DCS application. Therefore, it consists of the simplest hardware architecture and supports the emulation of multiple controllers. They will hereinafter be described in detail.

4.2 Target Machine

For easy simulator implementation, the HIACS-7000 series DCS emulator allows the actual DCS application software to be executed on a single PC without the need for any DCS hardware. Hitachi recommends the following minimum specifications for a PC running the HIACS-7000 series DCS emulator in Hitachi's latest ABWR training simulator:

- CPU: Intel® Core™2 Duo 2.4GHz
- Memory: 4Gbyte
- OS: Hitachi's Linux based real time Operating System

4.3 Software Architecture

Figure 3 shows the software architecture of the HIACS-7000 series DCS Emulator. The compiled application control software can run on a PC as if it were on a real DCS. Application programming by the user is limited to using Function Block Diagram (FBD). Programming with FBD (1) takes place in the Programming Tool environment; the Tool translates (2) the user-created FBD (1) into the Instruction Word Table (3), which is the same as that used in the real DCS. The Tool then loads the Instruction Word Table for every controller into Function Block (FB) instruction tables (4) in the DCS emulator. In the DCS emulator, the emulator task (5) is periodically activated by the task scheduler (14) and calls the emulator routine (8). The emulator routine then takes input data from the plant model (9), calls the FB instruction interpreter (10), and then sets the outputs to the plant model (11). When called, the FB instruction interpreter (12) takes the FB instruction words out of the FB instruction tables (4), and then calls the corresponding FB instruction routine (13) which is the same as that used in the real DCS. For a multi-controller emulation, the emulator task (5) executes each controller's software in sequence (7).

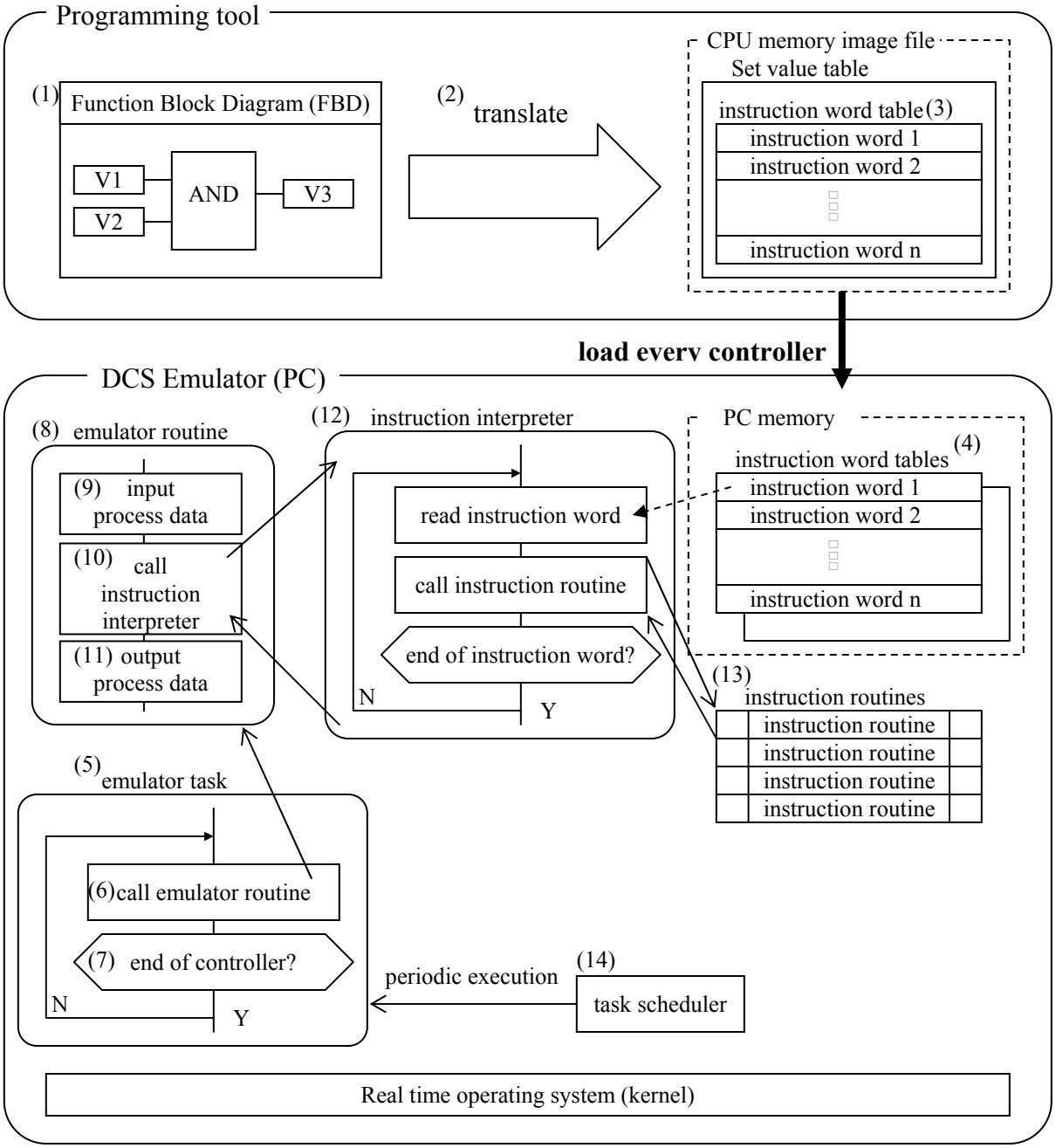

Figure 3 DCS Emulator Software Architecture

4.4 Communications

1. Inter-Controller Communication

The HIACS-7000 series DCS emulator can support the emulation of multiple [up to 128] controllers. The data exchanges between emulated controllers are implemented by writing to or reading from a shared common memory resident on the emulating PC.

2. Communication with physical controller(s)

Since it is necessary to exchange data between the emulated controller(s) and the physical controller used in the training simulator's interface system, the HIACS-7000 series DCS emulator supports a communications protocol that is identical to that used in the actual plant.

3. Communication with maintenance and programming tool

The HIACS-7000 series DCS emulator allows a user to use the Maintenance Tool "as is" to control directly emulator functions such as run, freeze, data forcing and monitoring.

4. Communication with plant model

Hitachi's ABWR training simulator plant model is developed internally by Hitachi's nuclear science laboratory. Since both the plant model and the HIACS-7000 series DCS emulator are implemented in a PC environment, plant model input and output exchanges with the DCS emulator take place by PC memory reads and writes.

4.5 Functions

The DCS emulator includes capabilities and functions that enable it to satisfy simulator requirements. A list of the most important of these functions follows:

1. Freeze/Run

When the running DCS emulator receives the FREEZE command, it temporarily stops its calculations, internal timer and counter. When the frozen DCS emulator receives the RUN command, it restarts the calculations, timer and counter from the point at which the FREEZE command was received.

2. Speed Up/Slow Down

The DCS emulator can change its calculation speed by preset selectable factors, for example, speed up by 2× and 5×; or slow down by ½×, 1⁄5×, and 1⁄10×.

3. Store/Restore

When the DCS emulator receives the STORE command, it stores the current state. The DCS emulator is able to store up to 100 states, such as the start-up conditions, rated output conditions, transient conditions and so on. When the DCS emulator receives the RESTORE command, it restores the selected stored state. These 2 commands are available only when the DCS emulator is in the FREEZE state.

4. Backtrack/Restore Backtrack

BACKTRACK is used during the "Running" state. BACKTRACK is automatically executed at every set time, and the state value is stored as a snapshot in the DCS emulator buffer. After that,

the snapshot is automatically stored in a file. The RESTORE BACKTRACK can retrieve the stored state for examination.

4.6 Performance

The HIACS-7000 series DCS emulator, when applied to the latest ABWR training simulator, can emulate over 60 controllers and execute a total of 60,000+ FBDs (usually a FBD consists of several FBs). The HIACS-7000 series DCS emulator's CPU utilization is about 13% in a 100ms cycle. With plant model added, the CPU utilization increases to around 16% of a 100ms cycle. This loading provides the CPU with has enough margin to allow a calculation speed-up of up to 5×.

5. Overview of G-HIACS NuSAFE Series DCS Emulator Development

Hitachi is currently developing G-HIACS NuSAFE, an IEC51508 SIL2 Functional Safety DCS platform with an IEC61131-3-compliant programming interface (HISEC61131-3FS) and the corresponding DCS emulator. This state-of-the-art DCS emulator can be applied to NPP simulators for plants using G-HIACS NuSAFE DCS. This section provides an overview of this latest Hitachi DCS emulator.

5.1 Target machine

Similarly to the HIACS-7000 series DCS emulator, the G-HIACS NuSAFE series DCS emulator also allows actual DCS application software to be executed on a single PC without the need for any DCS hardware. The PC's specifications are the same as those for the HIACS-7000 series DCS emulator PC (see above).

5.2 Target program

The G-HIACS NuSAFE DCS application software is able to contain both SIL2 Functional Safety (FS) and general-purpose (non-SIL) programs and run them on a single CPU. The G-HIACS NuSAFE series DCS emulator can execute both program types "as is" and with no need for any special user configuration.

5.3 Plant model

While the HIACS-7000 series DCS emulator must include a plant model, the G-HIACS NuSAFE series DCS emulator allows the user flexibility to communicate with a plant model residing on a separate PC. In this architecture, the G-HIACS NuSAFE series DCS emulator sends/receives plant process data to/from the plant model via OPC-DA (OLE for Process Control-Data Access). OPC is a published industry standard for system interconnectivity. OPC enables applications to exchange data on one or more computers using client/server architecture.

OPC defines a common set of interfaces so that applications retrieve data in exactly the same format regardless of the data source.

5.4 Typical architecture

Figure 4 shows a typical architecture for a simulator implemented using the G-HIACS NuSAFE series DCS emulator.

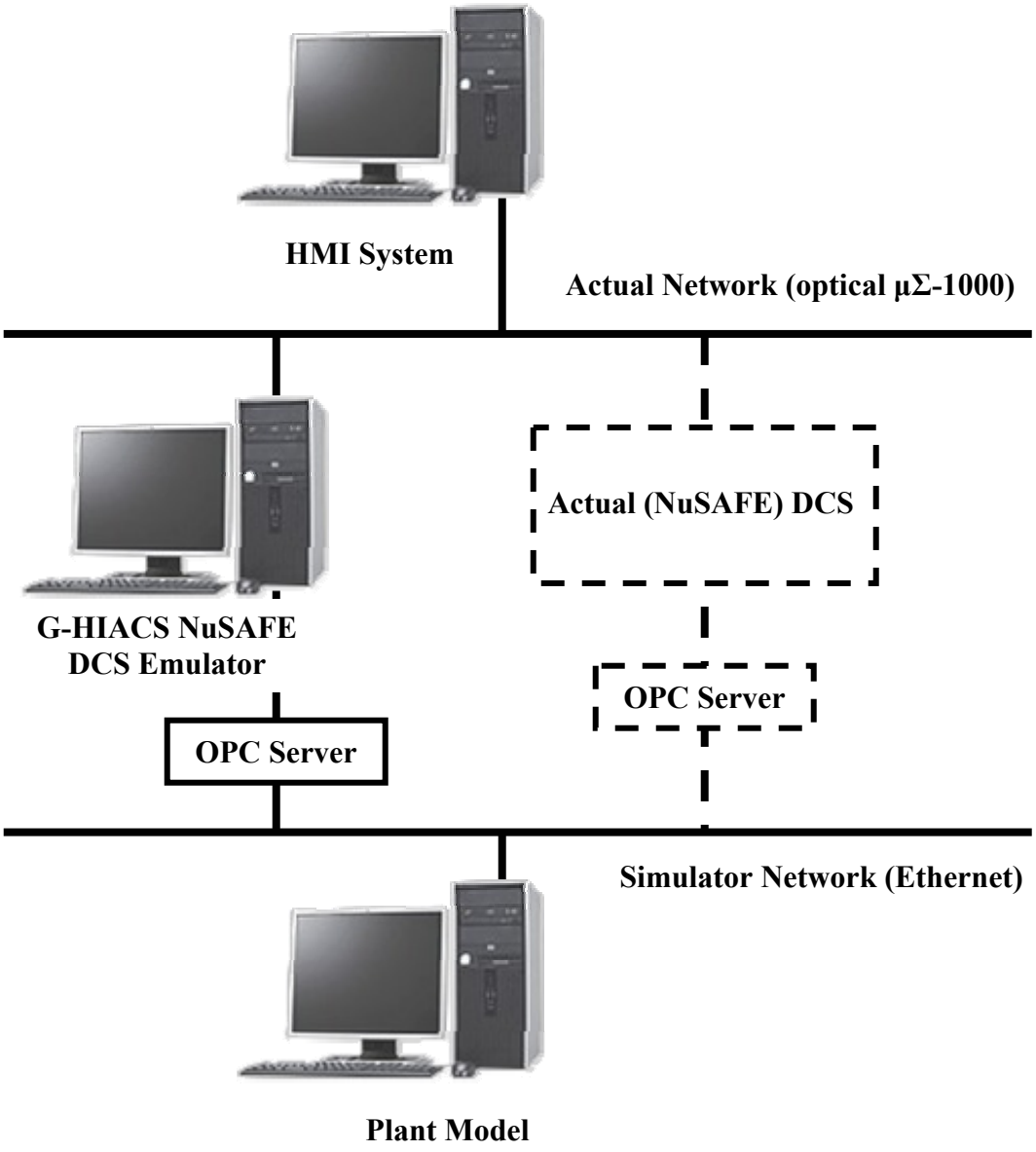

Figure 4 – Typical architecture of a G-HIACS NuSAFE series DCS emulator-based simulator

The Simulator Network (Ethernet) allows the G-HIACS NuSAFE series DCS emulator to connect to the Plant Model PC via OPC for plant process data transfers. The G-HIACS NuSAFE

series DCS emulator is also able to connect to same physical network medium and to send/receive data via the identical communications protocol (i.e., "Actual Network", Hitachi μΣ-1000) as that used in the real plant without interfering with the other simulator systems (e.g. HMI system) that are already on the Actual Network. One can also connect an "Actual (NuSAFE) DCS" to the Actual Network and have it communicate directly with the G-HIACS NuSAFE DCS emulator as though it were a real DCS. These G-HIACS NuSAFE series DCS emulator capabilities support robust and straightforward simulator implementation by allowing the DCS application and hardware to be used almost exactly as they would be in a real I&C system architecture.

6. Example of the application of the most recent ABWR Simulator

Figure 5 is a screen-shot of Hitachi's ABWR desktop virtual simulator. This simulator is also implemented on a single desktop PC. The desktop virtual simulator can be used for a number of activities from trainee self-study to multi-user classroom training sessions. The virtual wide display panel and main control panel are created by a 3-D model using OpenGL. A user can "enter" the virtual control room and manipulate the various panels as if in the real control room. The desktop virtual simulator, using only a partial NPP model but the same DCS emulator as that used for the Full Scope Simulator, can allow limited user training capability. Simulator functions, for example, Malfunction, Speed Up and Slow Down, are also supported. Hitachi is also studying on how to apply the desktop virtual simulator to new client requirements on maintenance.

Figure 5 - Screen-shot of the desktop virtual simulator

7. Conclusions

DCS emulator can handle the processing of an entire project or system in faithful real-time emulation of all application program software logic even loaded on multiple individual controllers. The Hitachi simulator solution package can provide the emulator function of the controllers making possible controller-less software verification with no significant modifications of the application program, the network communications or the system configuration. Hitachi is a “one-stop shop” able to deliver real-time full-scope plant simulator such as classroom training simulators and desktop virtual simulator and provide life-time support and service.

8. References

[1] Y. Nakashima, S. Masunaga and Y. Maruyama, “Hitachi Power Plant DCS Simulator Development”, 15th Annual Conference of the Institute of Electrical Engineers of Japan, Hitachi-shi, Ibaraki-ken, Japan, December 1, 2007.