Development of a Power Plant Simulation Tool with GUI based on General Purpose Design Software

Dong Wook Kim, Cheong Youn, Byung-Hak Cho, and Gihun Son

Abstract: A power plant simulation tool ('PowerSim') has been developed with 10 years experience from the development of a plant simulator for efficient modeling of a power plant. PowerSim is the first developed tool in Korea for plant simulation with various plant component models, instructor station function and the Graphic Model Builder (GMB). PowerSim is composed of a graphic editor using general purpose design software, a netlist converter, component models, the scheduler, Instructor Station and an executive. The graphic editor generates a netlist that shows the connection status of the various plant components from the Simdiagram, which is drawn by Icon Drag method supported by GUI environment of the PowerSim. Netlist Converter normalizes the connection status of the components. Scheduler makes scheduling for the execution of the device models according to the netlist. Therefore, the user makes Simdiagram based on the plant Pipe and Instrument Drawing (P&ID) and inputs the plant data for automatic simulating execution. This paper introduces Graphic Model Builder (GMB), instructor station, executive and the detailed introduction of thermal-hydraulic modeling. This paper will also introduce basic ideas on how the simulation Diagram, based on netlist generated from general purpose design software, is made and how the system is organized. The developed tool has been verified through the simulation of a real power plant.

Keywords: Graphic model builder, instructor station, netlist, component model, simulation solver.

1. INTRODUCTION

As the advanced computer technologies are being expanded to every field, the analog control equipments of power plants are being replaced with the advanced digital equipments such as DCS (Distributed Control System). Therefore, simulators are needed for training purposes or verifying the function of the DCS itself. Simulators are composed of simulation tool that includes plant system model, real-time executive, database, Instructor station and input/output control devices. Among them, plant system modeling requires a long period of time to be developed. The experienced technology of developing simulators can be applied to design for plant system modeling and verification codes. But developing simulators is different from developing plant simulation tools. The power plant system has various types of component such as heat exchangers, pumps, pipes, valves and tanks. Furthermore, the component-to-component connections for a power system are quite complicated. For simulation of the complex system, manual coding is very tedious and inefficient. It is very important to have the developing tool for constructing the simulators, which provides automatic processing and execution by putting the drawing of the plant systems and data. Also, the maintenance of the models results in many problems. Therefore, simulation tools based on GUI (Graphical User Interface) such as MMS (Modular Modeling System), PRO_TRAX and SIMPORT have been developed[1-3]. However, the existing simulation tools have the limitation in component expandability because of constructive problems and marketing strategies. The user who wishes to add his or her own component model algorithm into the simulation tool for a specific system, generally can not expand them. In Korea, however, power plant simulation tools are not yet developed and thus in order to develop a power plant training simulator or boiler/turbine control system

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Dong Wook Kim is with NETEC, 103-16 Munji-dong, Yuseong-gu, Daejeon 305-380, Korea (e-mail: dongwook@khnp.co.kr).

Cheong Youn is with the Department of Computer Science, Chungnam National University, 220 Gung-dong, Yuseong-gu, Daejeon 305-764, Korea (e-mail: cyoun@cs.cnu.ac.kr).

Byung-Hak Cho is with Korea Electric Power Research Intitute, 103-16 Munji-dong, Yuseong-gu, Daejeon 305-380, Korea (e-mail: chobh@kepri.re.kr).

Gihun Son is with the Department of Mechanical Engineering, Sogang University, 1 Sinsu-dong, Mapo-gu, Seoul 121-742, Korea (e-mail: gihun@sogang.ac.kr).

verification simulator, simulation tools have to be imported from other countries[4]. Along with the ten-year knowledge on simulators, research has been done to develop an independent power plant simulation tool. A simulation tool, PowerSim, operating in windows(NT) is developed by applying existing commercial software and general purpose design software as a model builder GUI. General purpose design software was used as a library of power plant component symbols such as heat exchangers, pumps, valves, tanks, and etc. From this, procedures for getting Netlist, which contains information on the relationship between each element and the procedures for constructing a simulator environment, was developed.

This paper describes a new simulation methodology for reducing cost and improving the expandability limitation of existing tools. Developing tool has the GMB in addition to the elements of the simulator. This paper introduces GMB, Instructor Station and the real-time Executive. This paper provides a description and algorithm of the thermal-hydraulic modeling of power plant components such as heat exchangers, pumps, pipes, valves, tanks and solver applied to the simulation tool, and system model fitted to Netlist, which was created from general purpose design software adjusted to the relation information to describe processes of simulating a power plant system. The tool developed has been verified through simulating a real power plant.

The power plant model applied in this verification is a feed water system of the Honam thermal power plant. This paper will also introduce basic ideas on how the simulation Diagram (SimDiagram) based on Netlist, which is generated from general purpose design software, is made and how the system is organized.

2. STRUCTURE OF POWERSIM

The PowerSim comprises four basic elements, which are the Graphic Model Builder called GMB, Instructor Station, Executive and Database. Fig. 1 shows its structural overview.

2.1. Graphic Model Builder

Graphic Model Builder is composed of Graphic Editor, Netlist Converter, Plant Component Library, Simulation Solver and Scheduler. The graphic editor creates and edits component icons and adds them into the component library. The graphic editor also provides SimDiagram with drawing functions that construct plant system objects to be simulated by placing graphical icons selected from the component library. The Netlist Converter transforms the output of the Simulation Diagram into a serial information lists to be used for modeling. The Simulation Solver calculates the plant dynamics with the netlist data received from the netlist generating from general purpose design software. The Scheduler makes an order for executing the device models, which are the subroutine for them.

2.1.1 General purpose design software and Model Builder

Since a power plant has complex connections of

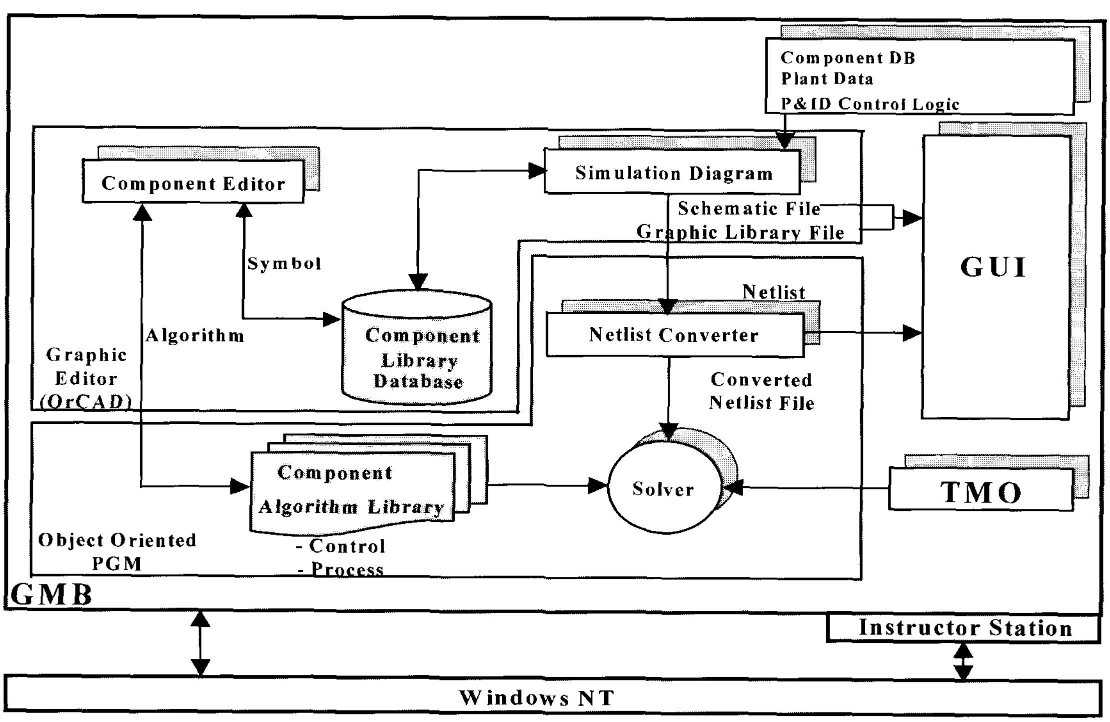


Fig. 1. Structural overview of PowerSim.

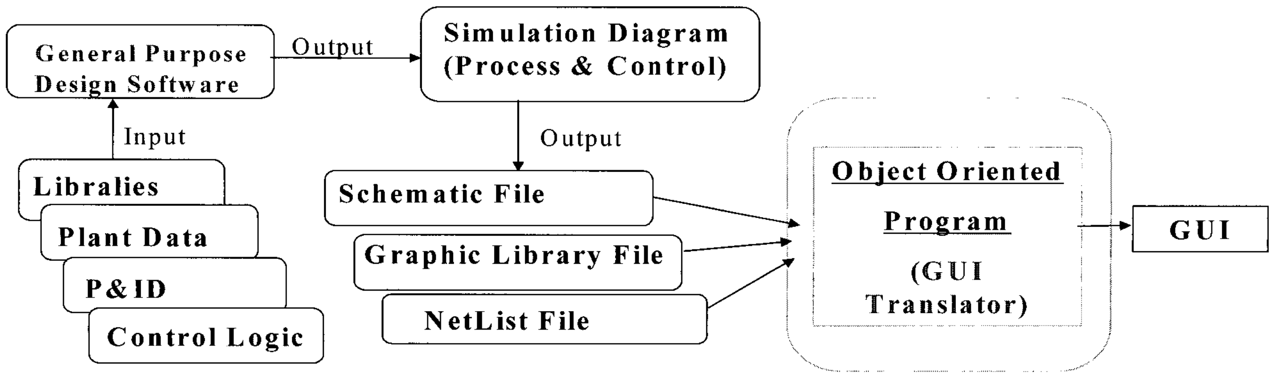


Fig. 2. GMB configuration using General purpose design software.

various components, the graphical procedures in which components are placed and connected with each other are essentially required for efficient system simulation.

Since developing a new graphic editor takes time, PowerSim uses general purpose design software, which is one of many commercial CAD programs. The general purpose design software has the advantages in managing the device symbols as library and providing information on connection status of the components for designing electric circuits. The component editor and library are used to enable users to add or change component icons. Users can create or change component icons and save the icons in the component library. Therefore in the present tool, the system design tool does not generate a source code for simulation unlike other commercial simulation tools which generates code. This may be more convenient for the general users. Once users complete a system design and execute simulation, the simulation can be executed immediately by the Executive. Fig. 2 shows the process of the automatic generation of GUIs for instructor station and dynamic plant models. First, a graphic library of component symbols should be made according to the order required for Netlist Converter. Then, SimDiagram should be made using the library, plant data, Pipe and Instrument Drawing (P&ID) and control logic.

General purpose design software provides a Schematic file (.SCH), a Library file(SRC) and a Netlist file(.NET) for each SimDiagram.

Since the Schematic file is made of binary that has the locating information such as symbol, line, text and so on, the file needs conversion to ASCII. And the Library file provides the width, height and graphic information of symbols. Other GMBs such as ProTRAX and SIMPORT use the graphic editor and the GUI at same time. But PowerSim generates the GUI using Visual C++ from the drawing information of the graphic editor.

Therefore, PowerSim can easily modify the functions of the GUI through the information from general purpose design software, although a limitation on the information general purpose design software can provide exists.

2.2. Netlist Converter

The Netlist Converter automatically generates dynamic models represented by the SimDiagram and normalizes the components symbols by the pin order using Netlist files, Schematic files, Graphic library files. Then the Converter makes the output files, '.CON', 'MAIL' which represent the connection status of the controlling symbols such as External Parameter (EP), Boundary Condition(BC) and the all symbols drawn in Simulation Diagram. If the Converter finds an abnormal connection, it makes a report file, '.RPT'. for the user.

2.2.1 Conversion of Control Simulation Diagrams

The last pin was selected for the output of the symbol in the Control SimDiagram. Fig. 3 shows the Converter normalizes the process of the Control SimDiagram.

Each connection status between the symbols is processed after normalizing. When all of the input pins connected to the symbols have the new values, the output pin sends the signal 'Active' to the next symbol so that it recognizes the inputs have been

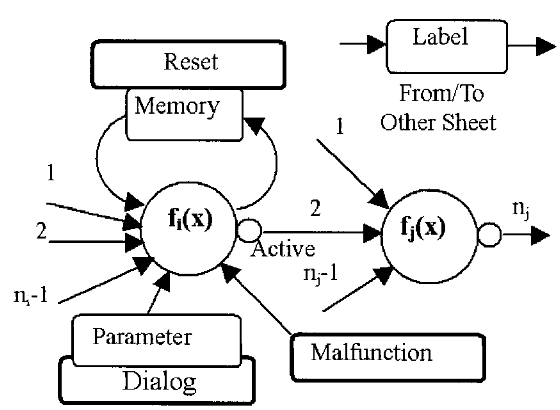


Fig. 3. Normalization of control SimDiagram.

updated. This is similar to the process of the feed forward in Neural Network. But, when the symbols have any inner feedback loop, they use the old values for the input pins. Mail Addresses for the 'Label' manages exchanging data between SimDiagrams. On the other hand, the Converter does not manage the Addresses in the same Simdiagram, since the Netlist makes the connection status automatically. Other connection to the symbol such as Reset, Malfunction, Parameter update and so on will be explained in Executive to be followed.

2.2.2 Conversion of Process SimDiagrams

Process is composed of pipes, pumps, valves, heat exchangers, drums and etc. The rules for connecting symbols in Process SimDiagram are more complicated than in Control SimDiagram.

Fig. 4 shows the Converter normalization process of the Process SimDiagram. When the fluid has two-way flow such as heat exchangers, the rule for connecting the symbols also has two ways as follow. That is, pin 1 and 2 are for primary flow and pin 3 and 4 are for secondary flow. Connecting rules of other pins are defined for each symbol. Boundary Condition (BC) is added for process simulation. The converter for Process SimDiagram needs Admittance Matrix for finding the pressure on the symbol. Inverse of the matrix gives the pressure difference between plant components. Then the flow rate is solved from the result. The temperature of fluid is caculated from the flow rate and the input and output of the heat energy.

2.3. Scheduler

Using the connection relationship from the Netlist Converter, Scheduler makes the environment and database which calls the subroutines of the device models for executing the system model in the SimDiagram. The Scheduler selects the input/output data between different SimDiagrams using the file, '.MAIL'. PowerSim makes the executable model by scheduling the subroutines for components. But other tools generate raw codes from the converter and executable files through compiling and linking.

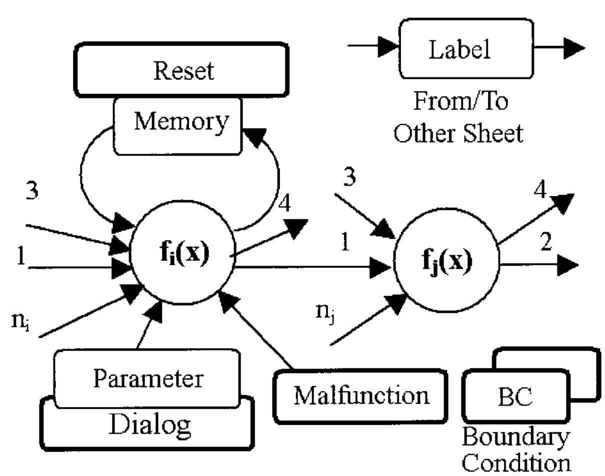


Fig. 4. Normalization of process SimDiagram.

3. INSTRUCTOR STATION AND GUI

Instructor Station provides many functions such as run, stop, Snapshot, Reset of the initial conditions, Trend Display, Remote Function to effectively operate the simulator. In addition, PowerSim has the advantage in integrating the GMB and the Instructor Station since it supports the function to add/delete the SimDiagrams. In other GMBs which generate raw codes, the parameters of the components should be selected in graphic editor and the executable file can be generated through compiling and linking. In PowerSim, the parameters can be selected through the dialog box of the instructor station during running. Therefore, it has the advantage of making the developing period of the simulator short.

3.1. Graphic user interface(GUI)

The basic information of the GUI is the Schematic and library files from general purpose design software. The graphic functions of the GUI are developed in the environment of the Multiple Document Interface (MDI) using the Microsoft Foundation Class(MFC) provided by Visual C++.

3.2. The functions of the instructor station

The relationship between the Instructor Station functions is shown in Fig. 5 as follows. These functions are represented from menus and dialog boxes supported by the Instructor Station. The Instructor Station has not only the function of controlling the simulator but also the function of appending the plant system models.

Fig 6 shows many functions of the Menu. Most important variables such as the functional output values of Control SimDiagrams, flow rates, temperatures, pressures of Process SimDiagrams are displayed on the space under each symbol. Other variables can be recognized and altered through the dialog box. The operation of the developed simulator can be worked on through a personal computer and the simulating environments can be stored at the database using the Snapshot of the Menu. Fig. 7 shows the dialog boxes of the PowerSim.

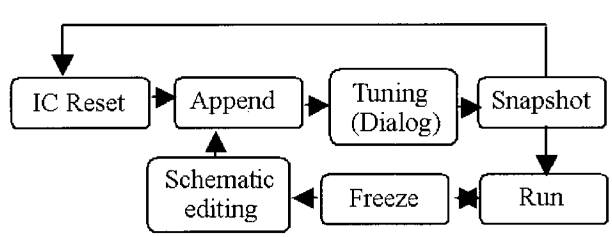
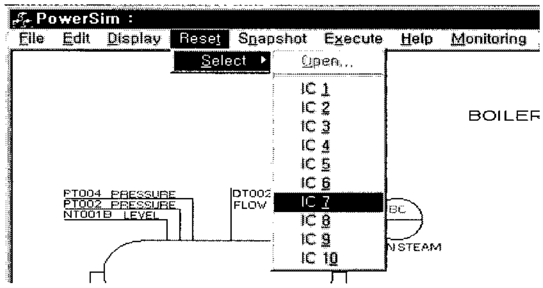
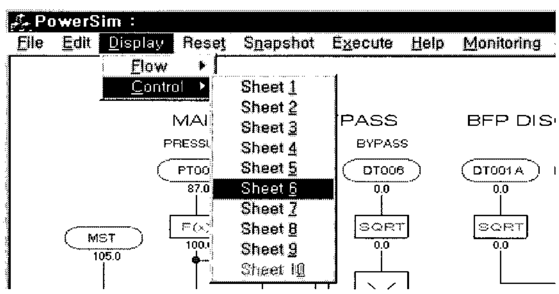


Fig. 5. Functional block diagram of the Instructor.

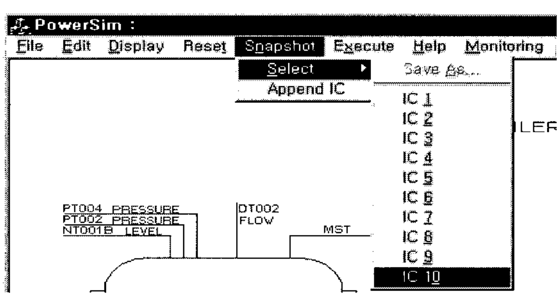


(a) Reset.

(b) Execute.

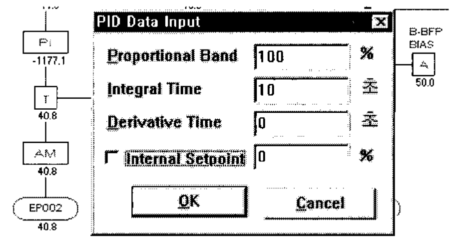


(c) Display.

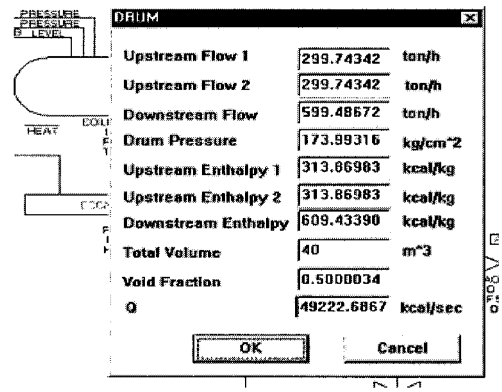


(d) snapshot.

Fig. 6. Instructor station menu.



(a) PID.



(b) DRUM.

Fig. 7. Instructor station dialog box.

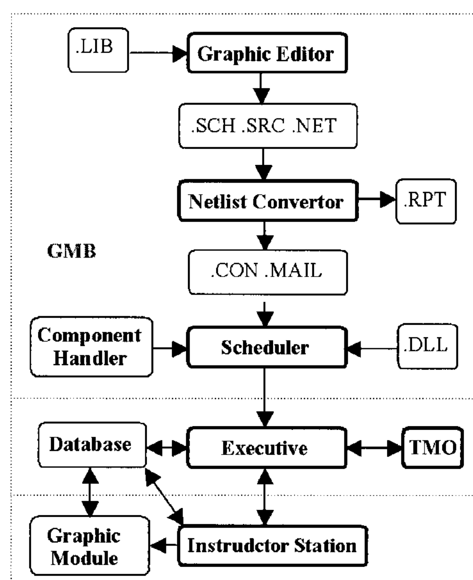


Fig. 8. Structure of the PowerSim.

4. EXECUTIVE

The Executive runs the dynamic model from Netlist and Scheduler in real time and writes the execution results on the database. It manages the Activities related to the User Interface. PowerSim selected Time-Triggered Message-Triggered Object system (TMO) for the real time Scheduler of the Executive, which is different from the Scheduler for the device models, explained in the previous section. The Scheduler has an important function in real time running for the whole simulator. TMO, developed in University of California at Irvine, is used for industrial applications in Korea nowadays. TMO supports the periodical scheduling by Time-Trigger and interruptible scheduling by Message Trigger. PowerSim uses only the Time-Triggered function. PowerSim is composed of GMB, Executive and Instructor station shown in Fig. 8. Database is made of the Structures of C language defined in the Document Class in Visual C++. Using the Snapshot via the Instructor station makes all the simulating environments store in the hard disk. In back, using the Reset with an initial condition reloads the environments from the hard disk.

5. IMPLEMENTATION OF THERMAL-HYDRAULIC(TH) MODELS INTO POWERSIM

5.1. Overview of TH models

Fig. 9 shows the interconnection between components such as heat exchanger, pump, valve, and tank. A node is defined as a point that interconnects each component. The conservation equations of mass, momentum, and energy are the governing equations of each component's thermal hydraulic phenomena, and they are represented as follows:

$$V\frac{d\rho}{dt} = F_{in} - F_{out}, \quad (1)$$

$$F = \alpha\Delta p + b, \quad (2)$$

$$V\frac{d}{dt}\rho h = F_{in}h_{in} - F_{out}h_{out} + Q + V\frac{dp}{dt}. \quad (3)$$

In (1)-(3), V and Q are the volume and inlet calorie respectively while a and b are the coefficients which are generally functions of pressure. F, h, and p are the flow rate, enthalpy, and pressure that are obtained from (1)-(3). The density, ρ, is determined from the equation of state which is a function of p and h. In the present model, the density is calculated from the equation of state used in RETRAN [6].

5.2. Simulation Solver

To solve for enthalpy and pressure, the energy and pressure equations should be solved. These equations can be solved from the connecting status of each component, and is obtained by the Netlist. From the information of the connecting status, the energy equation can be solved. On the other hand, to solve the pressure equation, the matrix solving process of following equation is needed:

$$A\vec{p} = \vec{q} \rightarrow \vec{p} = A^{-1}\vec{q}\,. \quad (4)$$

To get the real time simulation, the effective algorithm solver of reverse matrix is necessary. This matrix is a sparse matrix, but has no continuity due to the randomness of the component number. In addition, the matrix solver should be processed in each time step because the variables are functions of time. The basic concept of this algorithm is to skip the calculation of the element that is assigned zero. Fundamental methodology is the Gauss elimination method. Detailed process is described below.

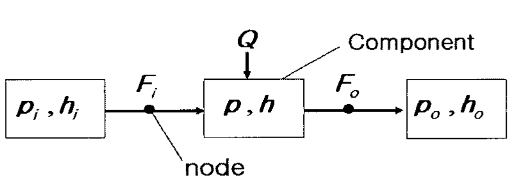


Fig. 9. Connections between components.

(i) Sequence of the matrix element that is assigned zero is continuously saved to specific matrix element that is assigned zero. Fundamental methodology is the Gauss elimination method.

(ii) Save the vector that has the sequence of operation in Gauss Elimination.

(iii) Save the matrix element that is assigned zero continuously and also save the vector P including the vector q in equation (4).

(iv) Operate according to the sequence that are stored in step (ii) and obtain the vector P that generates the pressure value.

In this algorithm, step (i) and (iii) are executed before calculating the model. In the step (iii) and (iv), the unnecessary operation on the vector elements that are assigned as zero is prevented.

6. VERIFICATION OF SIMULATION TOOL

The tool developed has been verified through simulating a real power plant. The power plant model applied in this verification is a feed water system of the Honam thermal power plant. Fig. 10 is an outline of the feedwater system of Honam thermal power plant schematized with AutoCAD.

6.1. Thermal modeling for Honam power plant

The feed water system of Honam thermal power plant is composed of a number of pumps, valves, heat exchangers, economizer, and boiler drum as shown in Fig. 10. The procedures of thermal hydraulic modeling of each component are presented in the following:

The two-phase flow of water and vapor exists in the boiler drum and the shell side of the feed water heat exchanger. Thermodynamic equilibrium is assumed for this condition. An explicit method is used to discretize the governing equations of a large volume such as drum according to time. In this case, the equation (1) and (3) are represented as follows:

$$\rho^{n+1} = \rho + \frac{\delta t}{V}(F_{in} - F_{out}), \quad (5)$$

$$(\rho h - p)^{n+1} = (\rho h - p)^{n} + \frac{\delta t}{V}(F_{in}h_{in} - F_{out}h_{out} + Q), \quad (6)$$

where δt is the time interval used in numerical calculation, and the upper n is the discretized time $n\delta t$.

To solve the equation (6), which has two unknowns (p, h), Newton-Raphson iteration combined with the equation of state, $\rho = \rho(p,h)$, is used.

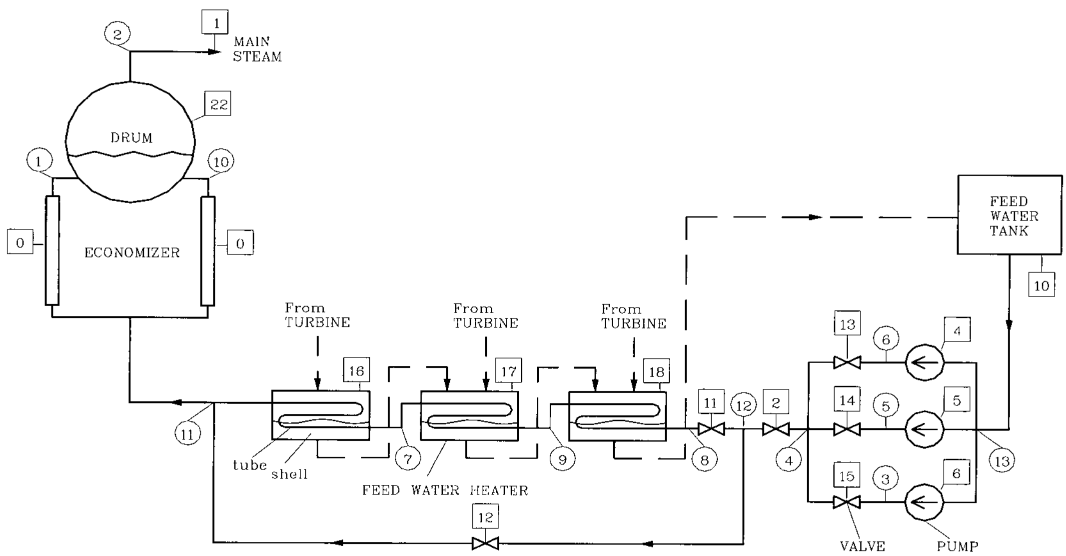


Fig. 10. Schematic of the feed water system of Honam thermal power plant model.

When applying the equation of energy conservation to the heat exchanger such as economizer or small components, the following implicit method, which has no limitation on time interval, is used:

$$h^{n+1} = \frac{V\rho^n h^n + \delta t(F_{in} + h_{in}^n + Q)}{V\rho^n + \delta t F_{in}}, \quad (7)$$

where the pressure variation is neglected since it is very small and the complete mixing (h_{out}=h) is assumed.

In the equation of heat transfer between tube and shell of the feed water heat exchanger, the two sections of drain and steam are calculated separately as follows:

drain section:

$$h_{sheel,out} = h_{shell} - Q_{shell} / F_{shell,out}$$
$$h_{tube} = h_{tube,in} + Q_{drain} / F_{tube}$$
$$Q = (UA)_{drain}(T_{shell,out} - T_{tube,in} - T_{shell} + T_{tube})$$
$$/ In[(T_{shell,out} - T_{tube,in})/(T_{shell} - T_{tube})]$$
$$Q_{drain} = Q_{drain} + a(Q - Q_{drain}) \quad (8)$$

steam section:

$$h_{tube,out} = h_{tube} - Q_{steam} / F_{tube}$$
$$Q = (UA)_{steam}(T_{shell} - T_{tube} - T_{shell} + T_{tube,out})$$
$$/ In[(T_{shell} - T_{tube})/(T_{shell} - T_{tube,out})]$$
$$Q_{steam} = Q_{steam} + a(Q - Q_{steam}) \quad (9)$$

In the above equations, the overall heat transfer coefficient(UA) is a function of the volumetric flow-rate and the void fraction. To solve the equation, a relaxation factor is adopted to solve the non-linear terms. It is determined as 0.1 after the sensitivity analysis. Momentum equation of the feed-water system is a function of the flowrate and the pressure. Most of the pressure loss in the loop is proportional to the square of the flowrate.

$$F = K\sqrt{\Delta p} \quad (10)$$

The K factor in (10) is determined based on the configuration of the loop. In this study, the overall pressure losses including those of the pump are considered as following:

$$F = \sqrt{C_1 \Delta p + C_2 N^2}, \quad (11)$$

where N is the speed of the pump and C1, C2 are the constants determined based on the performance curve of the pump.

To obtain the pressure and the flowrate, equation (11) is substituted into the mass balance equation and the following equation is obtained:

$$-a_{in}p_{in} + (a_{in} + a_{out})p - a_{out}p_{out} = b_{in} - b_{out}. \quad (12)$$

To solve (12) defined at a number of nodes, a matrix solver is needed because the pressure between the adjacent nodes should be obtained simultaneously. As shown in the Fig. 10, there are many kinds of volumes and the flow paths. Present study adopted an automatic method of calculating pressure using "Netlist" which is generated from the general purpose design software.

6.2. System configuration using the Netlist

As shown in Table 1, information between the connecting nodes can be generated based on the general purpose design software program. The component number represents a component type. The numbers assigned to each component are randomly

Table 1. Netlist file of feedwater system.

Component Connection List : c:/test/fw@flow.con

Node	Connected Components								Component Type			
	input				output							
	(#)	1	2	3	(#)	1	2	3	1	2	3	4
0001	1	0			1	22			208	203		
0002	1	22			1	1			203	207		
0003	1	8			1	16			201	202		
0004	3	14	13	15	1	2			202	202	202	202
0005	1	5			1	14			201	202		
0006	1	4			1	13			201	202		
0007	1	17			1	16			206	206		
0008	1	11			1	18			202	206		
0009	1	18			1	17			206	206		
0010	1	0			1	22			208	203		
0011	2	16	12		1	0			206	202	208	
0012	1	2			2	12	11		202	202	202	
0013	1	10			3	6	5	4	207	201	201	201

generated from the general purpose design software. Fig. 10 shows the connecting status. In this figure, the number in the circle means the node number and the number in the square shows the component information. Therefore, the Netlist file shown in Table 1 provides the most of system information and it can be used to generate the feedwater system model input.

6.3. Result of simulation

The input data for fluid-thermal model is given through a dialog box assigned to each component. In the simulation of water supply system, the pressure of a feed water tank and main steam is used for the boundary conditions of pressure equations. In Fig. 11, the digits displayed on components show calculation results of mass flow rate(F), enthalpy(H), pressure(P), level(L), and the position of a valve(y) when the level and pressure of a drum is maintained to 50% and 174 kg/cm^2 respectively.

As shown Fig. 11, the mass flow rate of inflow from the feed water tank equals to the mass flow rate of outflow into the main steam under steady state. This verifies that pressure equations governing the mass conservation are correct.

7. CONCLUSIONS

The power plant simulation tool PowerSim has been developed with new methodology. The functions of the PowerSim have been verified through the simulation of Honam power plant. The functions on Plant models and Instructor station were recognized as normal through simulating the level control system of the boiler. Generally, to develop a simulation Diagram for each system model of a power plant with conventional method takes about 16 hours by an expert developer. However, the same model was created in about 8 hours. It is recognized that tuning the simulator is easy and developing period can be shortened through integrating the GMB based on general purpose design software. Using general purpose design software, a commercial product, for GMB gives low cost for developing the PowerSim. The developed simulators through the PowerSim can be operated on PC and dose not require experts for

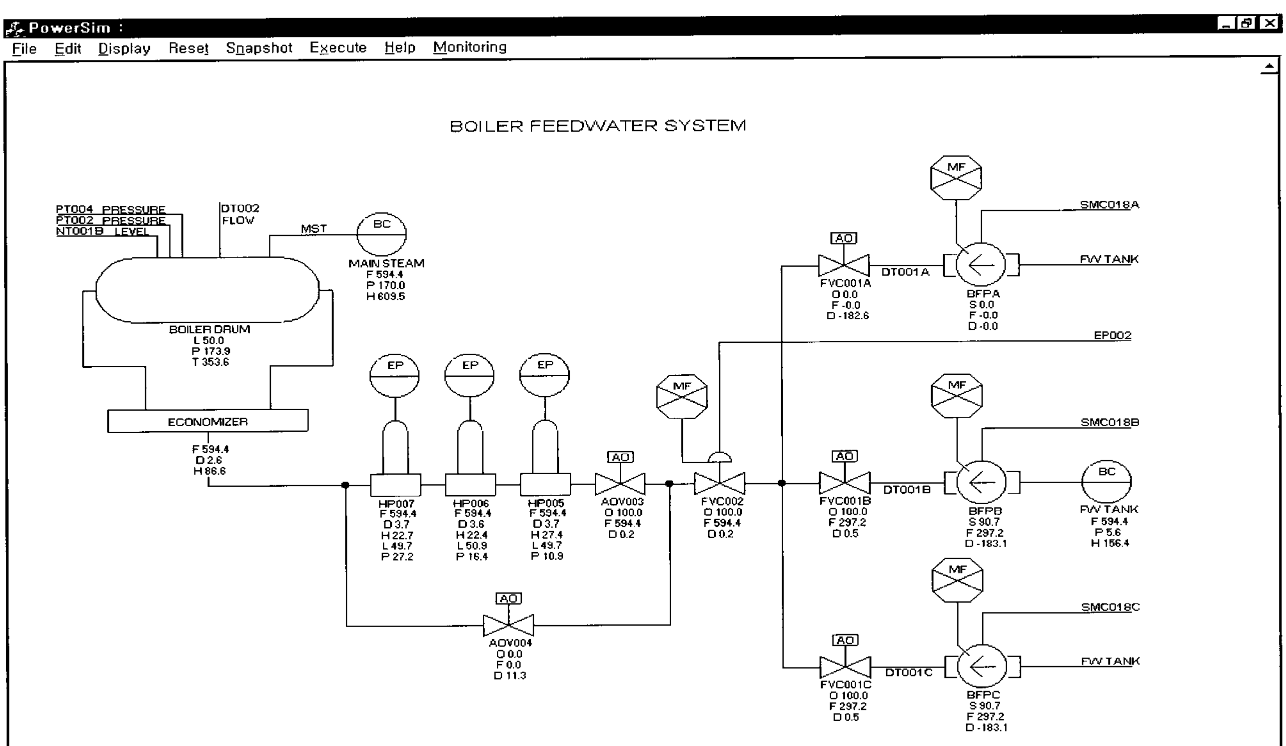


Fig. 11. Result of simulation of the feed water system of the Honam power plant.

operation. It is expected that the simulators will be very effective for training the plant operators and I&C engineers who have knowledge of CAD. PowerSim will be updated for development of full-scope simulator in the future.

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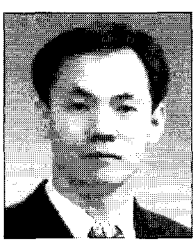
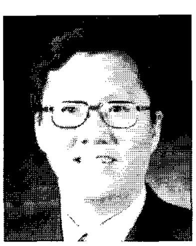
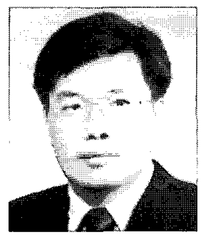


Dong Wook Kim received the B.S. degree in Computer Statistics from Honam University in 1995, and the M.S. and Ph.D. degrees in Computer Science from Chungnam National University 1999 and 2005 respectively. His research interests include system identification, software requirements analysis, and real-time simulation.



Cheong Youn received the B.S. degree in Physics from Seoul National University in 1979, M.S. degree in Computer Science from University of Illinois in 1983. He received the Ph.D. degree in Computer Science from Northwestern University in 1988. His research interests include software engineering, object oriented software system analysis, and system identification.

Byung-Hak Cho received the B.S. degree in Electrical Engineering from Han-Yang University 1982, and the M.S. and Ph.D. degrees in Nuclear Engineering from KAIST in 1986 and 1996 respectively. He has been a principal member of technical staff at KEPRI since 1990. His research interests include system identification, real-time simulation, and robots for hazardous environment applications.



Gihun Son received the B.S. and M.S. degree in Mechanical Engineering from Seoul National University in 1986 and 1988, respectively. He received the Ph.D. degree in Mechanical Engineering from UCLA in 1996. His research interests include multi-phase dynamics, heat transfer and power system simulation.