REAL-TIME SIMULATORS FOR GEOTHERMAL POWER PLANTS AND DISTRICT HEATING SYSTEMS

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ABSTRACT

The paper describes a real-time simulator for the high-temperature geothermal power plant at Nesjavellir, near Reykjavík, Iceland. The simulator is PC computer based and connects to the actual control hardware and operator interface. The simulator can he used for operator training, testing of control system hardware and software, analysis of various process design alternatives, and design and tuning of the control system. The paper introduces the basic architrcturc of the power plant processes and shows a comparison of ,simulation model transients with actual datu taken in the plant. The paper also describes a simplified version of the Nesjavellir power plant simulator, a district heating system simulator and a building simulator based entirely on Microsoft Windows programs and standard PC hardware In these simulators the control system is simulated instead of using the actual control hardware and operator interface. These simulators are compact and inexpensive, mainly intended for training, design evaluation, control system tuning and analysis.

1. INTRODUCTION

This paper describes a real-time simulator, intended both for training and design studies, for the high-temperature geothermal power plant at Nesjavellir, near Reykjavik, Iceland. The plant uses a steam and water mixture from nearby geothermal steam wells to heat cold water to 83°C, which is then piped 27 kilometres to the Reykjavik city area.

The Nesjavellir power plant simulator has been developed by the University of Iceland's Systems Engineering Laboratory and the engineering consulting firm Rafhönnun, with support from the Reykjavik Municipal District Heating Service and the Icelandic National Research Council. The main objectives in building the simulator are its use as a training tool for plant operators, in analyzing control and operation strategies. and for the testing of control system hardware and software (Haraldsdottir et.al. 1993a and h, Sigurdsson and Haraldsdottir 1993). The scope of the simulator model is the power plant itself, including the flow of steam from the production wells through all heat exchangers, and the counter-flow of cold water through the heat exchangers, deaerators, pumps and out to the main pipeline. The pipeline and city distribution systems are not modelled in this simulator.

Following the development of the Nesjavellir simulator three new simulators based on standard PC hardware and running under Microsoft Windows (Microsoft Corporation 1991) have been developed by Rafhönnun in cooperation with the Geothermal Training Programme of the United Nations University in Reykjavik, with support from the Reykjavik Municipal District Heating Service. The first of these simulators simulates a geothermal power plant, similar to the Nesjavellir power plant. The second one simulates a district heating system, including low temperature geothermal production wells, downhole pumps in thermal wells, pumping stations, storage tanks, peak load boiler station, transmission pipelines, distribution network and load model based on statistical model for typical weather variations. The third one simulates the thermal properties of a building and its environment.

Section 2 introduces the architecture of the Nesjavellir power plant processes. Section 3 describes the Nesjavellir simulator hardware, followed by section 4 that presents measurement results obtained in the plant, and compares actual transients with simulation results. In section 5 the new PC computer based simulators are described. Section 6 contains concluding remarks.

2. POWER PLANT DESCRIPTION

Figure 1 shows a flow diagram for the power plant at Nesjavellir. The geothermal production wells discharge a mixture of water and steam. This two-phase mixture is transported to a central separator station, where water and steam are separated. The steam is then piped to the power house, where any remaining moisture is removed in the mist eliminators. Presently, the steam pressure is lowered to about 2 bara using valves, before the steam enters the steam heat exchangers (condensers), but phase **2** of the plant development calls for the installation of steam turbines to utilize the pressure drop for electric power generation. Condensate is added to the low-pressure superheated steam to cool it to saturation conditions before entering the condensers. The water (brine) is piped directly from the separators to the powerhouse to preheat cold water in brine heat exchangers. The pressure of the high pressure steam is regulated to 15 bara by steam exhaust valves, and the water level in the separators is regulated by water exhaust valves.

Due to scaling, the geothermal fluid from the Nesjavellir field can not be used directly in the district heating distribution network. The power plant therefore uses the geothermal energy to heat cold ground water indirectly in the heat exchangers. The heated water is treated so that it can be used directly in the network.

Today the capacity of the power plant is 150 MWt, where about **88%** of the heat is transferred in the condensers, 8% in the condensate heat exchangers, and the remaining **4%** in the geothermal brine heat exchangers. In the future development of the power plant, the brine heat exchangers will play a more prominent role in the heat transfer.

After the cold ground water has been heated to 88°C it enters the deaerators, where oxygen is removed by boiling the water under vacuum. As the water boils, steam and gases rise to the top of the deaerators, where cold water is injected to condense the steam before the gases are ejected. The heated, oxygen-free water is then pumped up to a storage tank at Hahryggur, from which it flows by gravity the 27 **km** distance to the Reykjavik area. Two accumulators are installed near the power station, at the foot of the hill up to Hahryggur, to dissipate pressure surges caused by shutdown of the main pumps.

The planned capacity of the co-generation power plant is 400 MWt for district heating and over 80 MWe of electric power when fully developed. In its current capacity (150 MWt), the power plant is operated with six condensers, two deaerators, four plant pumps and three main pumps. For further detail on the design and operation of the Nesjavellir power plant the reader is referred to Gunnarsson et.al. 1991

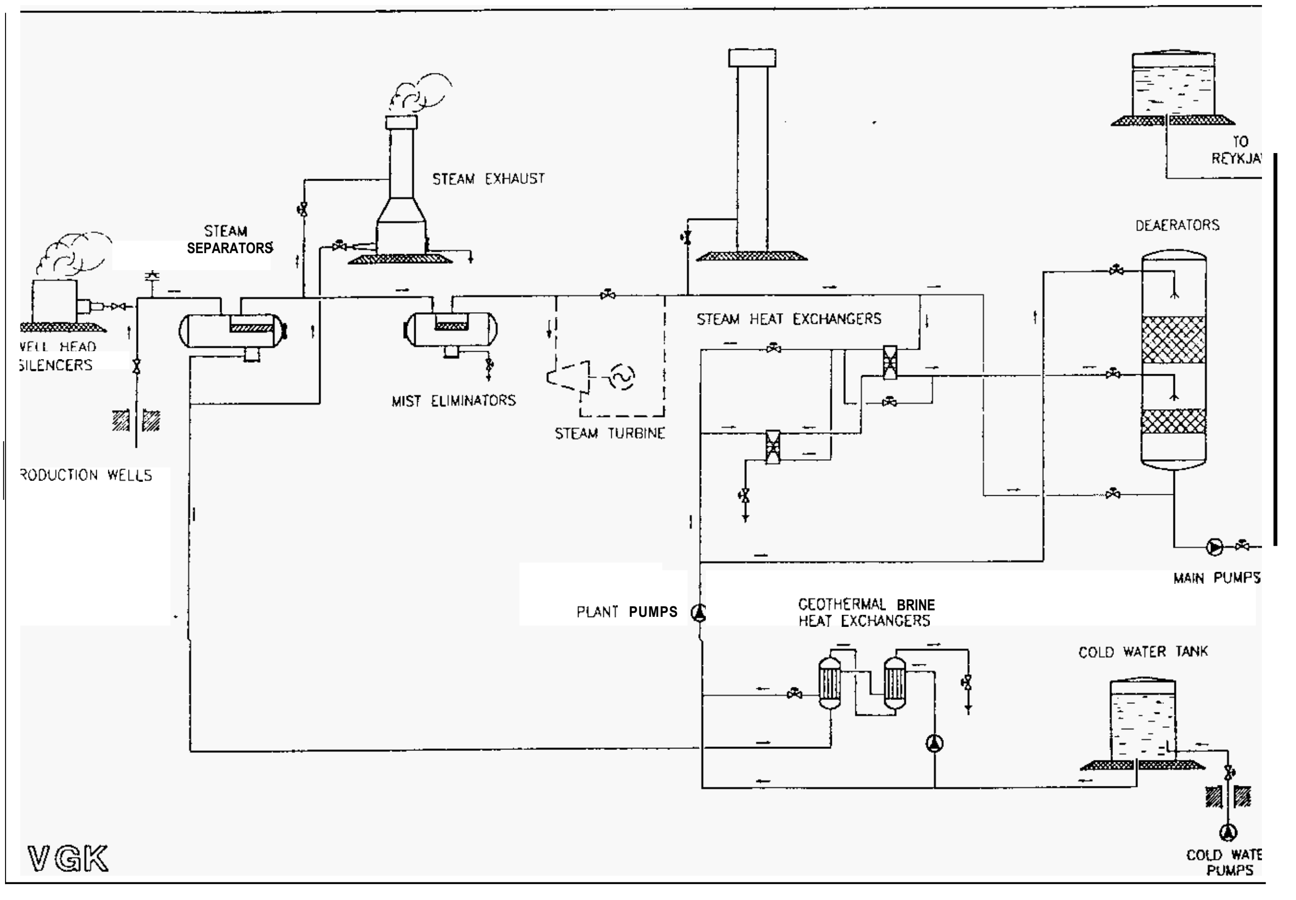

Figure 1. Flow diagram for the power plant

3. HARDWARE-IN-THE-LOOP SIMULATOR

A schematic of the Nesjavellir training simulator hardware is shown in figure 2. The simulator is composed of a PC 486 computer that runs the dynamic simulation of the power plant and interfaces to a TI565 industrial PLC computer, that is identical to the one used in the actual plant. As in the plant, the TI565 computer interfaces to a PDP11/83 SCADA (Supervising, Control and Data Acquisition) computer, that presents system information to operators through an ABB Tesselator display system. The operators give their reference control commands through the Tesselator, which relays information back the same way to the simulation model. Thus the training environment is identical to that present in the actual plant. An additional operator panel, for the training supervisor. is connected to the control computer, and is used to set up certain training scenarios such as equipment malfunctions.

4. VALIDATION WITH MEASUREMENT DATA

Measurements were taken in the plant during start-up in September 1992, to obtain data for validation of model components. The data was tapped off the communications between the TI565 process controller and the PDP11/83 SCADA computer, using a 3 second sampling time. In addition, during an emergency shutdown of the plant, data was collected using a 0.1 second sampling time to capture the fastest transients occurring in the main pipe (water-hammer effects).

Figures 3 to 6 show some typical transients measured in the plant together with corresponding simulated transients using the model. In these figures, the actual plant data is shown with dotted curves. In this experiment the power plant load was reduced by 18% in three major steps. The same experiment was run on the simulation model and the results compared to the plant data. The figures show that good agreement (including both dynamic and steady-state behaviour) is obtained here between the experimental results and the simulated ones. Figures 3 and 4 show comparisons of plant pump pressure and plant pump valve position. Figure 5 shows the temperature of heated water into deaerators, and figure 6 shows the temperature into the main pipeline. Similar agreement was obtained for most other variables. The only significant differences were found in the behaviour of some of the large steam valves, which is characterised by varying level of sticky friction.

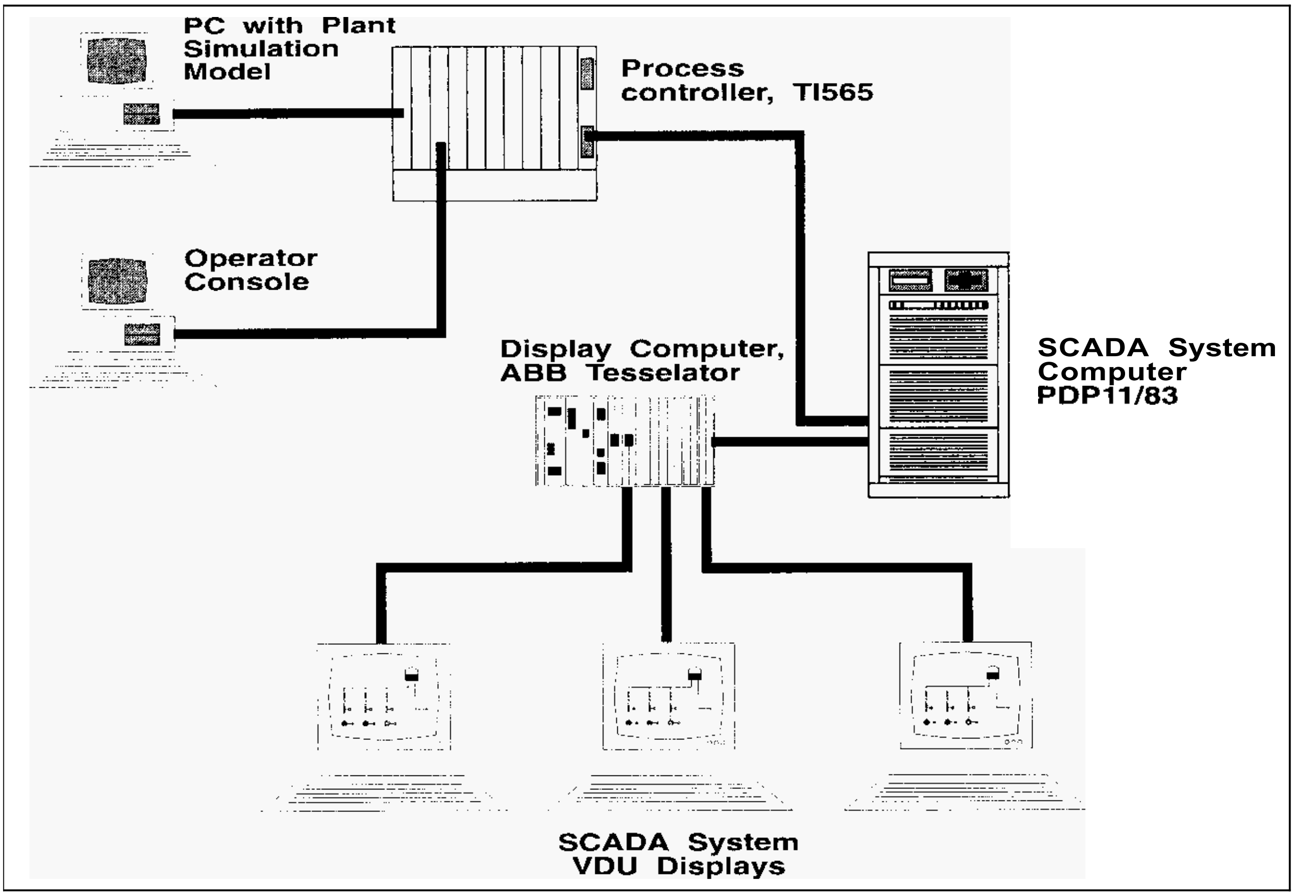

Figure 2. Configuration of the Nesjavellir simulator

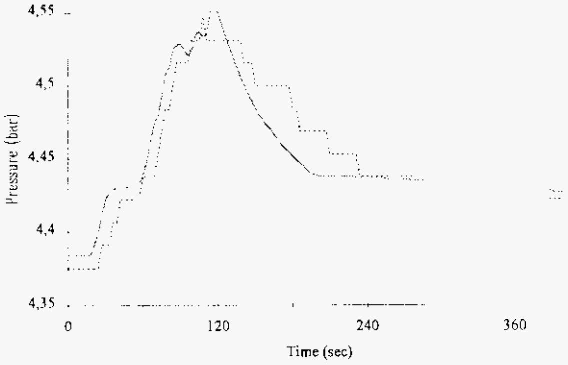

Figure 3. Plant pump pressure

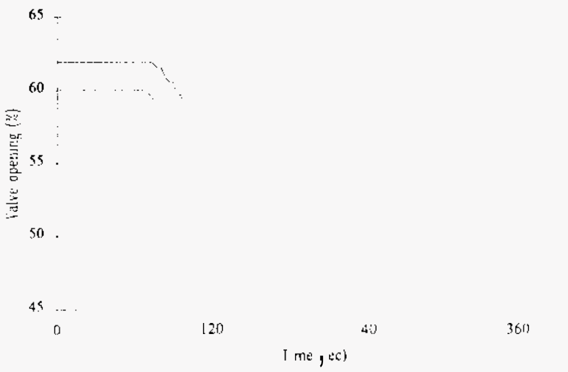

Figure 4. Plant pump valve opening

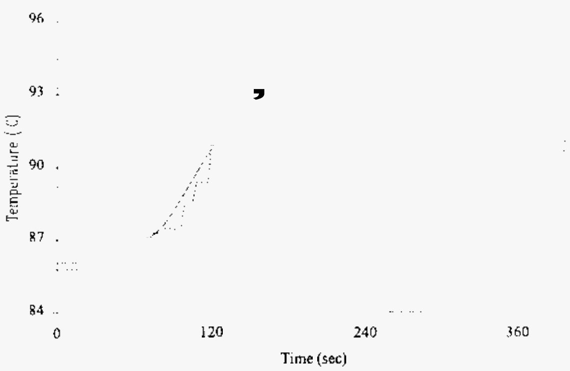

Figure 5. Temperature into deaerators

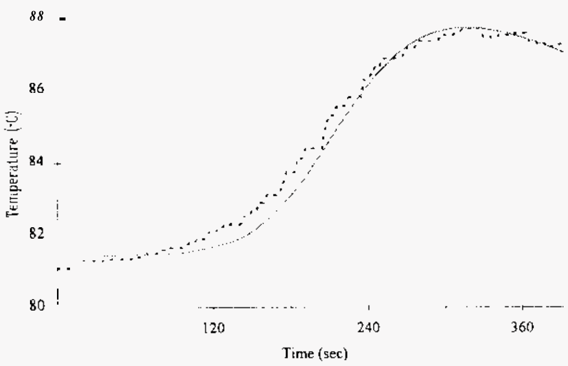

Figure 6. Temperature into the main pipeline

5. PC BASED SIMULATOR

In January 1994 the development of a PC based version of the Nesjavellir geothermal power plant simulator was started. The objective was to develop a low cost version of the geothermal power plant simulator that would appeal to schools and operators of small geothermal services. The development of this simulator was done in close co-operation with the United Nations University Geothermal Training Programme (UNUGTP) in Iceland. Over 130 engineers and scientists from 26 countries have completed the 6 month training programme at UNUGTP during the last 15 years. It was decided early on to make additions to the simulator so that it would cover a wider aspect of the existing geothermal engineering curriculum at the UNUGTP. A building simulator and a district heating system simulator where therefore added to the package. To facilitate the integration of the simulator into the curriculum the existing textbook used at UNUGTP; "Geothermal District Heating - The Iceland Experience" (Karlsson 1982) was used as a reference for the design of the building simulator. At the Mechanical Engineering department of the University of Iceland a course in geothermal engineering has been taught for several years. Homework from this course will he adapted to prepared training scenarios for the building and district heating system simulators. By integrating this existing teaching material, that has been used successfully for many years, with the simulator then the proper adoption of the simulator into the UNUGTP curriculum should be secured. Training scenarios are prepared by editing command files that define all relevant initial conditions and events for the simulation run. By making changes to the command files, the simulators can be made to simulate various types of district heating services, and can thus he adapted to the local conditions experienced by the UNUGTP students.

Figure 7 shows a simplified schematic of the PC based simulator. The hardware consists of two or more network connected PC computers, one or more for the simulation model and the graphical display and one instructor station for the training supervisor. In contrast to the Nesjavellir simulator, all programs (i.e. for the simulation model, the control system and the user interface) used in the simulator run on the same computer, or on several network connected computers. All programs run under Microsoft Windows and communicate with each other via DDE links. The simulation model is coded in the simulation language ACSL (Mitchell and Gauthier Associates), and the user interacts with the simulation through a graphical display, based on the industrial operator interface InTouch (Wonderware Corp.), that shows all critical variables as well as control functions. Plotting of variables can be done both during a run and after a run is completed. As in the Nesjavellir simulator, the simulated systems are modelled in considerable detail, using dynamic mass and energy balance relations and lumped-parameter approximations. Included in the PC based simulator are tools for dynamic analysis for control system design.

As mentioned before, three different simulators have been built on this platform. The geothermal power plant simulator comprises models of production wells, steam pipes, water pipe networks, heat exchangers, vapour-liquid separators, valves, actuators, deaerators, pumps, and discrete-time controllers.

The district heating system simulator comprises models of production wells, tanks, deaerators, pumps, transmission pipes and distribution network, peak load fossil fuel fired plant, customer models and discrete-time controllers. Various factors such as well capacity and enthalpy, well draw down coefficients, pump head and capacity, tank dimensions, pipe dimensions, pipe insulation and roughness, valve dimensions and characteristics, load characteristics, e.t.c. can be adjusted in the simulator models and their effects on system hehaviour investigated. The simulator can he run in two modes. One mode is intended for the study of district heating control systems and includes pipe pressure dynamics. In this mode emphasis is placed on the training in the use of modem control equipment, including SCADA system, Programmable Controllers and PID control. In the other mode a simplified and fast running model of the process is used, leaving out pipe pressure dynamics. This mode is used to study the long time aspects of different district heating system design alternatives. Up to several years operation can be simulated in one simulation run in this mode.

The building simulator is based on a dynamic model of the thermal properties of a building and its environment. It is assumed the building is heated with hot water radiators and it is possible to investigate the effects of insulation, air exchange, solar-heat and supply water temperature on heat loss and indoor temperature stability. Various factors, such as radiator sizes, insulation, window sizes and temperature controllers. can he adjusted in the simulator model and their effects on heat loss and temperature stability investigated. Outside temperature and solar-heat are generated in the simulator using statistical models for typical weather variations. The user has the option of programming severe weather conditions through the selection of parameters. The user also has the option to supply weather information in the form of a data tile.

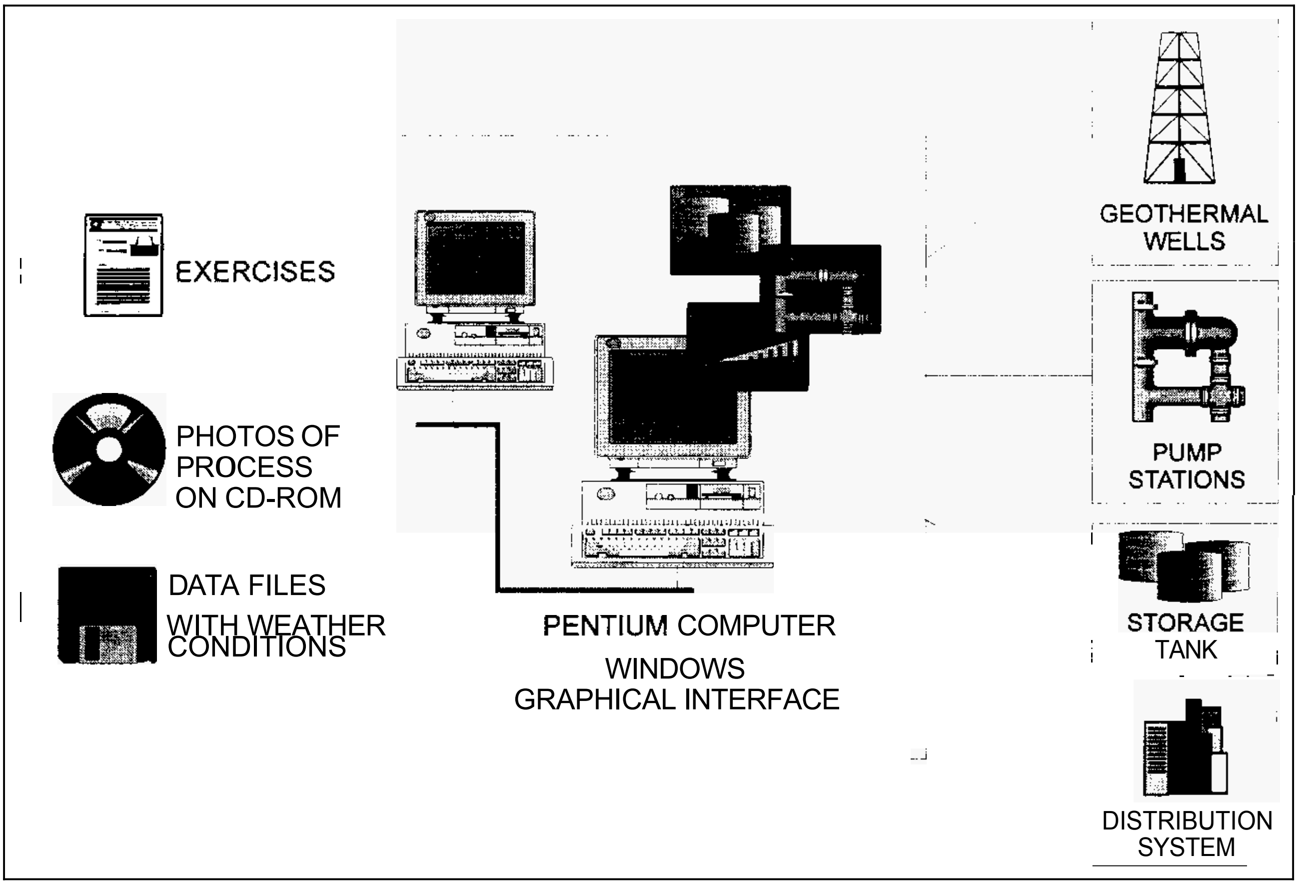

Figure 7. Configuration of the PC based simulator

6. CONCLUSIONS

This paper has described a real-time simulator for the Nesjavellir geothermal power plant. The model has been used as a tool in controller design for the plant, and as a training simulator at the Reykjavik Municipal District Heating Service. The model has been validated with actual plant data, and the simulation compares quite favourably with measurements in all important aspects. The model comprises just over 100 state variables and close to 1600 user-defined algebraic variables and parameters.

The paper has also described another less costly simulator for geothermal power plants and district heating systems. which has most of the advantages of the Nesjavellir simulator and runs on standard PC computer hardware and Microsoft Windows software. This simulator has been installed at the Geothermal Training Programme of the United Nations University in Reykjavik, Iceland. It will be used there to demonstrate to students various aspects of geothermal power plants and district heating systems.

Computer simulation has many advantages for both design engineers, operator personnel and engineering students. It can for example be used for:

- Analysis of various process design alternatives
- Development and analysis of control strategies
- Optimisation of operational strategies
- Tuning and adjustment of control systems
- Training of operators
- Testing of control system hardware and software

With the simulator, operators learn how to start up the process, run it under normal operating conditions and to handle malfunctions and process disturbances before the actual start-up of the plant. Control strategies can be tested thoroughly before plant start-up, and in the case of hardware-in-the-loop simulators (c.f. the Nesjavellir simulator) programmable controller programs and hardware can also be tested. All of this shortens the time needed for initial plant start-up and also reduces the risk of equipment damage during start-up and operation. Expansions and modifications will also require less time and be less costly. Design engineers can easily analyse different plant designs and optimise operation. This reduces the risk of unforeseen costly process modifications.

Computer simulation also has many advantages as a teaching tool for educational institutions. With the help of simulators, students become quickly familiar with the simulated systems and can interactively perform various design studies.

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