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APROS: AN ADVANCED PROCESS SIMULATOR FOR COMPUTER AIDED DESIGN AND ANALYSIS

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APROS software has been developed for computer aided design and analysis of various processes. The process to be studied can be defined utilizing a grafic user interface. The symbols, connections and parameter values specified are stored in a database. The system is very flexible due to a combination of a user interface and an integrated solution method, where equivalent companion models are formed from nonlinear implicit differential equations and material properties describing the simulated process. An example set of power plant process and automation system components are presented and a nuclear power plant application is described.

Introduction

The advanced process simulator (APROS) has been developed in a three year co-operation project between Imatran Voima Company and the Technical Research Center of Finland, started in 1986. The aim was to design and construct an efficient and easy to use computer simulation system for process and automation system design, evaluation, analysis, testing and training purposes. According to the fields of application basically nuclear and fossile power plants were considered. Lately application to dynamic modelling of chemical plants was started. Besides the processes the automation system components have been modelled in detail. Also electric power supply and consumption are considered. A special process definition language was developed, which enables to use the simulation program from a conventional terminal and establishes the communication change between grafic workstation software and the simulation program.

Users define, by means of a terminal or a workstation, a model of the process to be simulated and the conditions under which the simulation experiments are to be performed. The definitions are made on a conseptual level so that the resulting model description in the database is modular, i.e. the data is associated with real process components like pipes, valves and pumps. A workstation with graphic software package can be used as a more convenient user interface than basic command language.

System Composition

APROS comprises a software environment with a flexible user interface for performing simulation experiments, called the executive system and optional simulation software libraries (figure 1). The basic version of APROS comprises one main program that interpretes commands given by users and according to them manages the database and controls the duration of simulation experiments by calling various model subroutines. APROS software is written in FORTRAN-77.

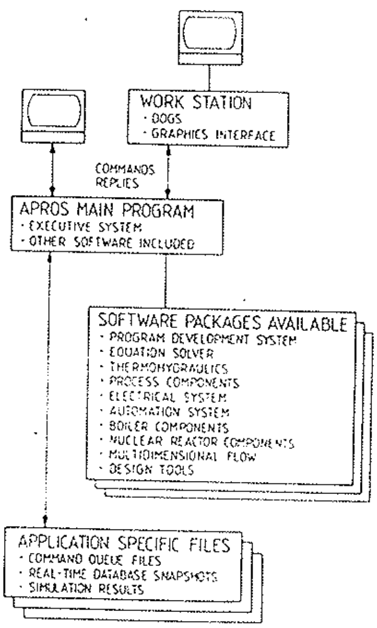

Figure 1 The composition of APROS

The general form of easy to use commands is:

OPERATION OBJECT ATTRIBUTES_OF_COMMAND

where OPERATION defines the function to be performed, OBJECT the target of the function and ATTRIBUTES_OF_COMMAND define more precisely the meaning of the command. Usually OBJECT is a database entity. An example of the commands is:

MODIFY PUMP1 PUMP_SPEED = 100.

Command queue files provide a macro facility for executing a sequence of APROS commands.

APROS database is kept in the main memory during simulation. APROS model programs utilize and update the data in the database during program execution. Therefore the database is called a real time database. At any time the current instance of the real time database can be saved into a file, snapshot file, containing a complete state that can be used as an initial state for simulation. The data in the database constitutes a modular model description. The data is organized as entities, modules, consisting of attributes, which initialy have values given by user. The values of the attributes are stored in variables used also in simulation software during simulation experiments. In addition to modules representing the actual data needed in performing simulation experiments the database contains, for instance, information specifying the structure of the modules.

APROS modules define e.g.: an experiment to be performed, the model description of a process or limited part of the process to be simulated and control of simulation experiment. The modules defining a model of the system to be simulated form a hierarchical model description. In principle, the model description consists of two levels: the definition level and the calculation level. The definition level consists of component groups forming subprocesses and processes. The highest level is the whole process plant under study.

Software packages

A set of software packages have been developed: system software associated with the command interpreter, the data management system and the basic output subroutines, system service subroutines enabling the command interperter and data management system to be called from user written subroutines, mathematical software such as sparse matrix subroutines for solving linear matrix equations, software for solving thermohydraulic systems and models of various process components.

Solution Principles

The initial state for a simulation experiment is calculated according to the model description stored in the database. The model description is the input data to process component models. When solving a thermohydraulic process, the calculations are not performed merely on the basis of process components. The process component models calculate input data for subroutines solving the conservation equations of mass, momentum and energy for the whole process. When solving these equations the process is considered as a network consisting of nodes and branches. The nodes of the network are control volumes connected by branches. The input data calculated by process component models contains e.g. heatflows to and from the nodes of the flow network and loss coefficients of the branches. Heatflows are calculated by heat exchanger models and loss coefficients by valve models, for instance.

There exists various accuracy levels for nodes and branches. For example, solving flow composed of separated liquid and vapour phases requires a more detailed model than solving flow composed of homogenous mixture of liquid and vapour. However, basicaly the problem is reduced to solve matrix equations where sparse matrix techniques are utilized /1/. Material property functions are used in calculating various quantities according to pressure and enthalpy.

Use of the System

The simulator will have a large and inhomogenous group of users. The users of the simulator can be classified in the three major groups, process and automation system designers, process analysers and model developers. The educational background of different users can vary very widely. Most of the users are not experts in programming, in mathematics or in physics. The requirements of the accuracy and the speed of the calculation are quite different for the designer and for the analyser. The exploitation of synergy between plant design and plant analyses is one of the main ideas that was recognized when starting the development project of APROS. By means of APROS the designer and the analyser can use the same simulation environment and database.

APROS can be considered as a CAE-package for plant design and analysis. The use of APROS during the power plant project can be divided in the five stages; design project, commisioning of the plant, afterwards modifications of the plant, plant analyses and training of operators.

Construction of the process and automation system models will be done during the design project of the plant. At this stage all the data fed to the database of APROS is based on the construction data of the plant components. The design engineer can assure his plans by simulations before commisioning. When making simulations he also trains himself for the commisioning of the plant. At this stage the modifications of the plans are much easier to make than during commisioning of the plant. Simulation of the plant at this stage can be considered as one kind of quality assurance tool. If the process model that has been constructed is detailed enough, it is also possible to test the function of automation cabinets before the process itself is ready.

During the commisioning of the plant the first measurements will be got from the real process and the simulation results can be compared with these. The simulation models can be tuned to get better compatibility between the measurements and the simulations. The comparison of the plant measurements and the simulations is possible if there exists a good interface between simulation computer and the process computer.

Afterwards during the normal operation of the plant, there could be need of some modifications of the process or automation system. If this kind of modifications will be done, they can be checked beforehand by simulator. If the model of the plant is already available it is easy to make the modification to the models.

Process analyses of the plant are not bounded to any specific stage of the power plant project. Special feature of these analyses is the high accuracy level of the simulation models. Some of the process analyses should be done during design project, when the measurements from the plant not exist. The basic process data for these analyses is got from the database of the process designers. The simulation model developed during the design project and during commisioning of the plant can be utilized both for initial training and retraining.

Component models

The automatic systems models include: analog and binary measurements, different kind of controllers and other components needed to build up closed loop control system, protection and interlocking systems, sequence control circuits for start up and shut down subprocesses and change over automatics.

Some typical power plant components developed are the pipes, pumps, valves (control, shut-off, relief and stop valves), tanks, heat exchangers, turbines for the description of steam expansion and electric systems including generators.

Specific components for nuclear power plants are: the reactor models to describe, in the simplest case the point kinetics phenomena, in a second approach the axial neutron flux shape and in the most sophisticated case 3-dimensional behaviour and the pressurizer including spray valves and heater groups for the description of a pressure and water and steam volume.

Specific components for fossile power plants are the boiler to describe flue gas and water and steam flow phenomena as well as heat transfer from flue gas side to water and steam side and the fuel supply system including the function of mills and burners.

Simulation Example

As an application example of APROS, the simplified model of a nuclear power plant has been formed. Model consists the reactor, two primary circuit loops, pressurizer, two steam generators and the secondary circuit loop from the feedwater tank to the turbine valves. Also the control system has been described; five control loops and the interlocking systems for 11 process devices (figure 1). In this paper the simulation of feedwater pump trip is briefly described (figure 2).

When the feedwater pump is stopped, also reactor will be tripped automatically, and after the steam pressure has decreased to 4.3 Mpa the turbine valve will be closed (driving time of valve is supposed to be 60 sec.).

From the users point of view, the computation time is important. It would be very nice to get the simulation results as soon as possible. The simulation model used in the test consists approximately 200 differential equations. The simulation computer is VAX-8650 and the CPU- time consumed to the simulation is app. 0.2...0.4 sec/calculation step depending on the number of iterations needed to get the solution that fullfils the given convergence criteries.

The time step that can be used in simulation depends on the state of the process. When the process is in equillibrium state, the calculation step can be set much longer than

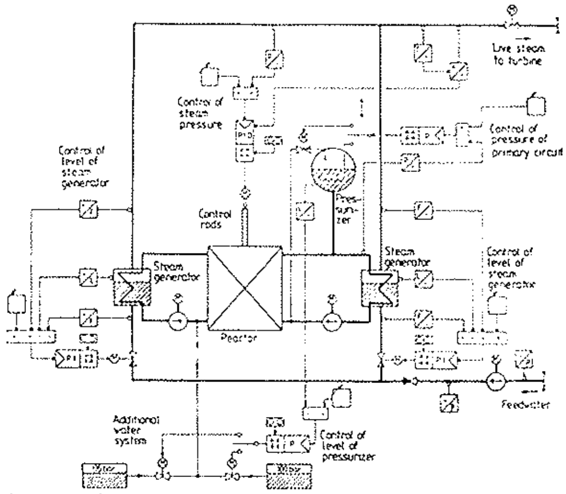

Figure 2 The process diagram of the test process

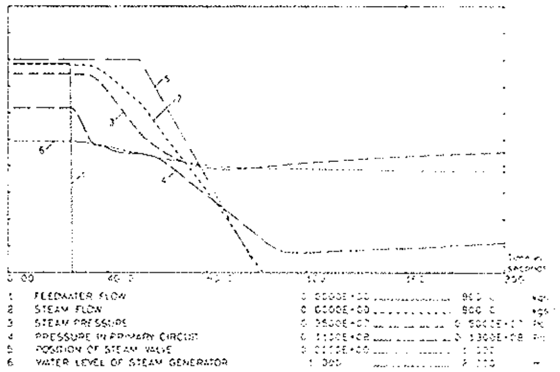

Figure 3 The feedwater pump trip

when some disturbance is just effecting to the process. In the simulation of feedwater pump trip, the time step of 0.5 seconds was used and the simulation of 200 seconds (400 time steps) took about 122 seconds CPU time. The automatic control of the time step is quite essential aid for the user, who does not know anything about mathematics or process models.

Conclusion

In this paper a new simulation environment for process and control system design and analyse has been described. The described system, APROS, is a very efficient and easy to use tool for simulation of different kind of processes and control systems.

The total scope simulation application of a peat fired power plant has been started in autumn 1987. Also other application and verification projects will start in the near future.

References

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