A MODULAR APPROACH TO MODELING POWER PLANT SYSTEMS

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Introduction

Power plants are large, non-linear systems with numerous interactions between its component parts. In the analysis of such complex systems, dynamic simulation is recognized as a powerful method of keeping track of the myriad of interactions . A simulation can be used to answer the "what if" questions that are asked when replacing components, changing operational procedures, or training operators.

While there are many applications for the simulation of power plant components and systems, its use is often discouraged because it can be difficult and expensive. Power plant engineering is itself a multi-disciplinary field involving fluid mechanics, heat transfer, thermodynamics, chemical engineering, nuclear engineering, and electrical engineering. Simulation requires, in addition, knowledge in model formulation, computer programming, and numerical solution of differential equations. Even with knowledgeable personnel, development of a sophisticated simulation requires large investments in engineering time to formulate, code, test, and document. Through a modular approach to dynamic simulation, MMS increases the effectiveness of available personnel and reduces the time required to develop simulations.

History

In 1978 the Electric Power Research Institute (EPRI) contracted with Bechtel and with B&W Nuclear Service Company (BWNS) to develop the Modular Modeling System. The initial development spanned six years, during which extensive testing and validation was performed. Pre-release testing of MMS was conducted by separate utility groups who were trained and assisted by the developers under the guidance of EPRI.

The initial version of MMS (MMS-01) was released at a workshop, hosted by Duke Power in April 1983. A second workshop, hosted by Middle South Services in September 1984, introduced the remainder of the MMS code (MMS-02) and thus completed the MMS development.

In mid-1983, recognizing that the MMS development effort was nearing completion, EPRI decided that the most effective way to promote continued use and enhancement of the MMS and accomplish the widespread transfer of the MMS technology to the utility industry, would be through the efforts of a dedicated commercial organization. In 1984, BWNS was chosen by EPRI to provide those commercialization activities.

BWNS became responsible for promoting the use of MMS worldwide, supporting further enhancements, and assisting users on specific applications. With the combined effort of EPRI and BWNS, the MMS code was transformed from research status to a widely used analytical tool for plant design, operation, and scoping safety analysis.

Since 1984 BWNS has revised and augmented the module library and accompanying documentation. New modules include control models, advanced reactor models, and a gas turbine model. Conversion to use SI units in addition to US units is currently in progress. MMS, developed on mainframe computers, is now available on more computer systems, including personal computers and mini-computers. Software to supplement MMS has also been developed.

Objectives of the MMS

The MMS makes simulation more cost-effective by providing the following advantages:

- Cost in engineering time is reduced by the use of pre-engineered models of plant components, eliminating the need for development of component models and avoiding the costs of model formulation, coding, testing, and documentation.
- The requirement for specialized knowledge is reduced by using a high-level simulation language, which provides integration algorithms, control analysis algorithms, and convenient input/output features, such as plotting and interactive input/output.

Developing a simulation of a complex system continues to be demanding and challenging. The MMS, however, significantly reduces the difficulty and the engineering time. Applications for the MMS include:

- Design and checkout of control systems
- Improved diagnosis of plant performance
- Procedure evaluation
- Specification, selection, and integration of plant components
- Plant simulator qualification
- Digital Feedwater Control System--Hardware-in-the-Loop
- Training

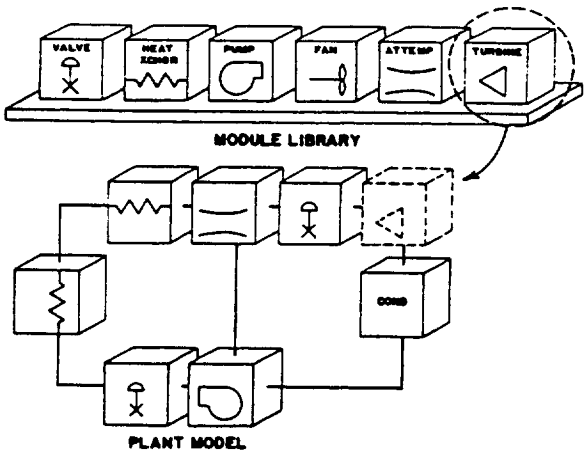

Figure 1--MMS functional concept

Modularity

The functional concept of the MMS is illustrated by Figure 1. Software modules were developed to correspond to plant components that are familiar to power plant engineers. The interface specifications of the modules have been defined so that the modules can be interconnected analogously to components in the actual plant. For some complex components, e.g. a nuclear reactor, several modules of differing complexity are available. These alternative modules allow an analyst to select the module appropriate to his application, i.e. a detailed model or a more economical model of less detail.

The modular nature of MMS allows an analyst to tailor the scope of a simulation to the complexity of the application. A simple simulation can be easily created, yet the structure of the MMS can also accommodate complex simulations.

In the development of complex simulations, it is important to be able to subdivide the simulation for more manageable development and testing. One approach might be to independently develop detailed subsystem models for later integration into a larger simulation. An alternate approach might be to start with a simplified prototype model which can be developed easily and be used in an early stage of development to decide how the model may best evolve into a more detailed simulation. The modular nature of MMS supports and encourages the use of either approach.

Module Library

The MMS Module library contains over 160 modules for components for nuclear and fossil plants. Table I lists the types of modules available. Each module is a mathematical model of a type of major plant component formulated from first principles. MMS modules are pre-engineered--that means that formulation, coding, testing, and documentation of each module has been performed and completed by engineers experienced in the simulation of power plant components. Users of the MMS benefit from the investments in engineering time made to develop the modules. Through a modular approach to dynamic simulation, MMS reduces the time required to develop simulation and increases the productivity of engineering personnel.

Simulation Language

The high-level simulation language used in the MMS is ACSL (Advanced Continuous Simulation Language). A simulation language provides features to simplify the development of simulations. Features especially important to the development of the MMS are

- o Macro capability
- o Automatic sorting of modeling equations
- o Integration algorithms

The most important feature of ACSL with respect to modularity is its "macro" capability. An MMS module is an ACSL macro which expresses the modeling equations for a single type of component. Since modules may be used more than once in the same simulation, naming conventions must be established to avoid name conflicts and to provide communication between modules.

MMS modules are ACSL macros following MMS naming conventions. Variable names consist of a basename and a suffix. The suffixes are arguments passed to the macro when it is invoked. One suffix, called the "Module ID," is different for each macro invocation. The module ID is appended to basenames to generate unique variable names for each macro.

Other suffixes, called "Stream ID's", are used to form variable names in common with other modules. In MMS a stream ID is associated with each stream connecting two modules. When a name is to be common between two modules, each module uses the same stream ID. For example the outlet enthalpy calculated by one module is the inlet enthalpy needed by another module. Each module must uses "H" as the basename for enthalpy. The ID used by the inlet stream of one module is specified to be the same as the ID used by the outlet stream of the other module.

The automatic sorting feature of ACSL arranges the order in which each equation is evaluated, regardless of the order in which the macros are invoked. Thus, the user may interconnect the modules without concern for the order in which the macros are invoked.

The integration algorithms offered by ACSL relieves the analyst from having to code a numerical solution to the modeling equations. The analyst

Table I--List of component types modeled by MMS modules

Fossil Modules
- Steam-to-Air Heat Exchanger
- Spray Attemperator
- Forced Circulation Furnace
- Natural Circulation Furnace
- Economizer
- Enclosure
- Once-Through Furnace
- Pulverizer
- Regenerative Air Heater
- Superheater
- Ducts
- Damper
- Combustion module
- Fans
- Compressor/Combustor/Gas Turbine

Control Modules
- Actuators
- PI Controller
- PID Controller
- On-Off Controller
- Delay Relays and Logic Delays
- Differential Pressure Transmitter
- Level Transmitter
- Function Generator
- Signal Follower
- Signal Monitor
- Hand/Auto Station
- Multiplier
- Auctioneer
- Summer
- Proportional Plus Offset
- Linear Scaling
- Difference Unit
- Bias Unit
- Logical Transfer
- Proportional with Hold
- Integral with Hold

Balance of Plant Modules
- Trapped Gas Accumulator
- Condenser
- Water-to-Water Heat Exchanger
- Hydraulic Coupling
- Deaerator
- Flash Tank
- Closed Feedwater Heater
- Electric Drive Motor
- Pipes
- Centrifugal Pump
- Drive Turbine
- HP Steam Turbine
- LP Steam Turbine
- Valves
- Flow Dividers
- Flow Junctions

Nuclear Modules
- Boiling Water Reactor
- Moisture Separator Reheaters
- Once-Through Steam Generators
- Pressurizers
- Pressurized Water Reactors
- U-Tube Steam Generators

Advanced Reactor Modules
- Helium-to-Air Heat Exchanger
- Helium-to-Water Heat Exchanger
- Sodium-to-Air Heat Exchanger
- Sodium-to-Sodium Heat Exchanger
- Water-to-Air Heat Exchanger
- Water-to-Water Heat Exchanger Model
- Sodium-Cooled Reactor

may choose from the seven integration algorithm offered by ACSL or he may include coding to define an algorithm of his own. The algorithm recommended for MMS is the Gear algorithm, a variable order, variable step size method that is both efficient and suitable for the stiff equations that often occur in power plant modeling.

Documentation

The documentation of the MMS consists of

- Theory Manual
- Programmer's Manual
- User's Manual

The documentation of each MMS module consists of sections in both the theory and the user's manual.

The theory manual describes, for each module, the component modeled and its scope of application. It also discusses the formulation of the modeling equations, the effects modeled, the effects not modeled, and the limitations of each model.

The user's manual consists of user worksheets for each module that identifies all parameters and initial conditions required to specify the model. Some modeling parameters, such as heat transfer parameters, are not readily available. Detailed instructions for each module guide the analyst in collecting component physical data and operating point data to simulate his actual component. To guide the user through calculation of those parameters, each worksheet contains parameterization instructions, which includes the equations, formulas, and handbook data.

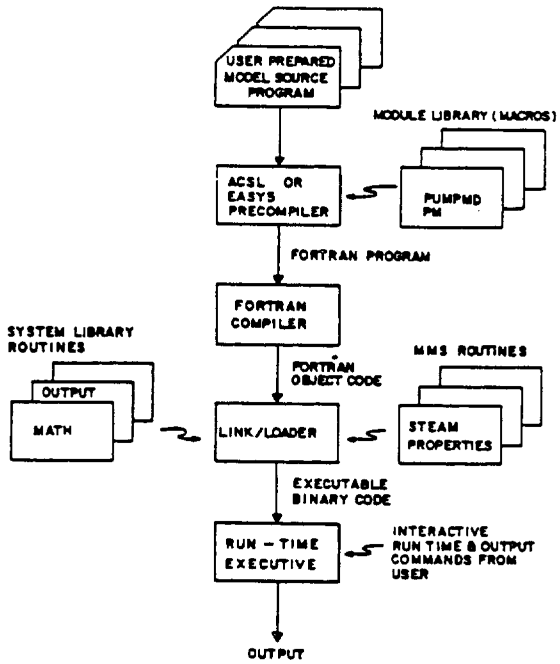

Figure 2--Processing an MMS model file

Building and Using an MMS Simulation

The major steps in building an MMS simulation are:

- o Select modules
- o Prepare a block diagram interconnecting the selected modules
- o Assign ID's to each block and each "stream" interconnecting the blocks
- o Collect physical and operating point data for each component.
- o Calculate parameters with the guidance of parameterization instructions and complete the MMS User Worksheets for each module.
- o Enter the ID assignments and the component data into an ACSL model file.
- o Process the model file as illustrated in Figure 2 to produce an executable program.

After generating the executable program by the above steps, ACSL runtime commands allow the analyst to start, stop, and continue a simulation. The runtime commands allow displaying, printing, plotting, and redefinition of almost any variable in the simulation. A long simulation can be interrupted and its state variables be saved for later restart and for the study of alternate scenarios. The runtime commands include several relatively new capabilities to perform frequency domain analyses.

MMS is supplemented by several software packages:

- o MMS-EASE+ is PC-based software used to allow the user to interactively select and interconnect modules interactively of a graphics CRT, to enter the physical and operating data into on-screen forms, and to perform the parameterization calculations automatically. .EASE+ forms can be printed with the user supplied data to provide convenient documentation.
- o PC-MATLAB is PC-based software which performs matrix computation and uses files ACSL produces to perform several different kinds of control analyses.

Summary

Productivity is significantly improved whenever it is possible to build upon work previously done. The MMS provides a mechanism to capture the extensive engineering effort already expended to formulate, code, test, and document component models. The MMS module library and documentation is the culmination of tens of thousands of engineering manhours. This accumulated expertise is available through the use of the MMS.