6TH

POWER PLANT DYNAMICS, CONTROL & TESTING SYMPOSIUM PROCEEDINGS

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6TH POWER PLANT DYNAMICS, CONTROL & TESTING SYMPOSIUM PROCEEDINGS

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Edited by
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Vol. 1 of 2

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FOREWORD

The College of Engineering at the University of Tennessee, Knoxville, along with the Department of Nuclear Engineering and the Measurement and Control Engineering Center, is pleased to sponsor the Sixth Power Plant Dynamics, Control and Testing Symposium. We want to acknowledge the cooperation of the Instituto de Investigaciones Electricas, Mexico, the University of Arizona, Department of Nuclear and Energy Engineering and the IEEE Control Systems Society. Many thanks to Freedia Tyson and Barbara Kelmers who assisted us in all facets of the symposium.

The purpose of the symposium is to provide a forum for experts to consider current and future problems in the dynamics, simulation, control, diagnostics and fault detection of power generating stations. The papers compiled in these two volumes deal with power plant modeling and simulation, testing, advances in data processing, power plant control, operator assist systems, plant monitoring, fault detection, expert systems and applications of artificial intelligence methodology.

We want to thank the contributors and the attendees for their participation.

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EPRI COMPACT ANALYZER

A COMPACT, INTERACTIVE and COLOR-GRAPHICS BASED SIMULATOR FOR POWER PLANT ANALYSIS

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ABSTRACT

This paper presents the results of an EPRI sponsored project (RP2395-2) for design and development of an interactive, and color graphics based simulator for power plant analysis. The system is called Compact Analyzer and can be applied to engineering and training applications in the utility industry. The Compact Analyzer's software and system design are described. Results of two demonstration systems for a nuclear plant, and a fossil plant are presented, and the applications of the Compact Analyzer to operating procedures evaluation are discussed.

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1 INTRODUCTION

The advancements in analytical modeling of power plant components and processes, combined with the developments in the computer field, have made possible the development of high fidelity compact simulators. These simulators offer cost effective alternatives to the currently available engineering and training simulators.

Full scope training simulators are generally large facilities offering a control room mock-up, and are mainly used for operator training. These simulators reproduce a plant response under normal and predefined abnormal conditions. Most of these simulators utilize correlation and table lookup based modeling techniques. Because of the high initial and operating cost, only a small fraction of the fossil-fired power plants in the US are equipped with a full scope training simulator.

Engineering analysis usually requires high accuracy, and therefore the modeling is based on the fundamental physical laws. These simulation packages are generally designed for a batch mode operation, in which a user "sets up" a simulation model, predefines the time sequence of the model inputs and external events, and submits it for execution. When the simulation is finished, the user analyzes the results which are usually printed or plotted on computer print-outs. If a problem modification is necessary, the above process is repeated. This process usually requires an expert for the simulation model set-up, and analysis of the results.

The usefulness of an engineering simulation package can be substantially increased if its user can view the simulation results on a CRT screen, and alter the model inputs, as the simulation is in progress. Such a system can fill the gap between the training and engineering simulators, and have a broad set of applications in nuclear and fossil-fueled power plants. This paper describes a system with these characteristics, called Compact Analyzer. It combines the EPRI Modular Modeling System (MMS)[1] dynamic simulation package with an interactive color graphics software for operation on typical mini computers.

1.1 Current Trends In Compact Simulators

A number of compact training and interactive engineering simulators are being offered now. The compact training simulators are generally a scaled down version of the full scope simulators, i.e., they offer a compact control board on which the key plant parameters are displayed and offer a simplified control panel with hard wired switches and lights. Generally, a fixed number of transients can be simulated with these simulators.

Engineering applications usually require accuracy and flexibility which can only be offered by first-principles simulators. Most of the engineering simulators are offered by the Steam Cycle vendors, and they consist of dynamic simulation codes, usually propriety to the vendor, and a user interface system for display of the simulation results. C-E's Nuclear Steam Supply System (NSSS) performance simulator [2,3] is an example which is composed of simulation codes for the NSSS, and a micro-processor based display system. The simulation is performed in a batch mode on a mainframe (CDC) computer and the simulation results are transferred and displayed on a remote display system. Most of these engineering tools are not interactive, i.e., engineer will set-up the problem and submits it for a batch execution, and reviews the results once the simulation is finished.

Other related activities include the development of nuclear power plant analyzers for The US NRC. This is a highly accurate, and faster than real-time, simulation system which can be used on-line by the plant operation personnel for "what-if" type questions during accident and normal operations. Two nuclear plant analyzers are being developed under the NRC support, one at Brookhaven National Laboratory (N.Y.) [4], and the other a joint project at Idaho National Laboratory (Idaho Falls) and the Los Alamos National Laboratory (New Mexico) [5]. The Brookhaven system is based on a special-purpose microcomputer (AD-10) with parallel-processing architecture, and a supporting mini computer. AD-10 is capable of fast numerical integration of differential equations representing the plant dynamics. As is reported, the cost of running an interactive on-line simulation with this system is "several order of magnitude less" than that of simulation on large machines, such as CDC-7600 or large Cray computer. The Idaho-Los Alamos development has emphasized on interactive graphics, driven by a large mainframe computer, Cyber 176 or Cray 1.

2 COMPACT ANALYZER SYSTEM SPECIFICATIONS

The basic characteristics of the Compact Analyzer are summarized below:

- o The simulations are performed on a mini computer DEC-VAX or PRIME.
- o The user interface is composed of one (or several) high resolution color graphic monitor(s) as the operator console, and one monochrome monitor and keyboard for instructor console. Several different devices including Chromatics CGC-7900, IDT and IBM-PC with graphic capability are supported. An IBM-PC/AT with a high resolution graphics monitor is currently being used as the user interface device. The simulation results are presented to a user through dynamically updated graphic pictures.

- An interactive Display Builder/Editor is provided for customization of the graphic pictures. For example, the display screen can be divided into different regions for display of alarms, simulation results, user control functions, and X-Y plots. The user is able to select displays from a library of pictures for dynamic update. The displays are composed of process schematic diagrams, engineering plots, numerical text and alarm messages. Offline tools are provided for construction and modification of user displays.

- The instructor console provides menu driven facilities for the start, termination, and control of the simulation process.

- The Compact Analyzer software is highly modular and can be easily modified and reconfigured for different applications. User can implement and interface application modules with the Compact analyzer in a simple manner.

- The software is coded in ANSI FORTRAN 77.

- Utilizes MMS simulation package. It consists of a library of modules such as pumps, pipes, heat exchangers, etc., operating in the Advanced Continuous Simulation Language (ACSL) [6] environment.

2.1 Software Design

The Compact Analyzer software design with an IBM-PC workstation for user interface is illustrated in Fig. 1. Each major software function is implemented as a separate module. These modules operate in parallel and communicate with one another through a shared global data base. The main software functions include Numerical Simulation Module, Graphics Display Driver Module, and Instructor Console Driver Module. New software modules can be added, and interfaced with the system through the global data base, without any impact on the existing modules.

Numerical Simulation Module performs the simulation process. It is composed of the executive and run-time portions of the ACSL package and a user MMS model.

During the simulation, the listed outputs are transfered to the global data base on a fixed time intervals. The distributed software structure of the Analyzer allows installation of multiple simulation modules in parallel. For example, a plant model, and a control system model can be implemented in two separate simulation modules.

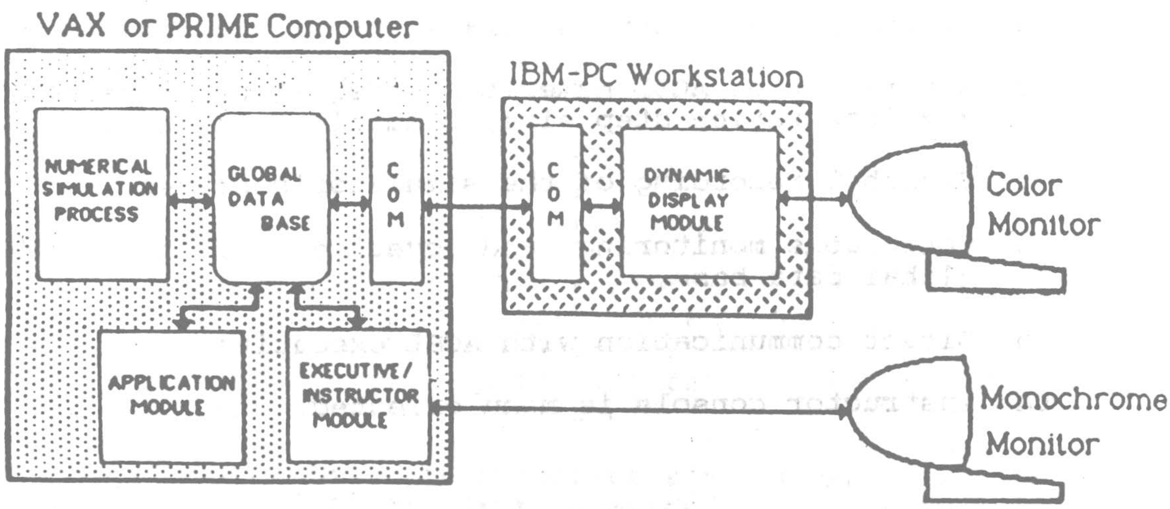

Fig. 1: Compact Analyzer Software Design

Graphics Display Module is responsible for drawing and dynamic update of pictures on color graphics monitor(s). It performs the following functions:

- o Let user prepare displays from a library of picture elements,
- o Draw the selected picture in a user defined window on the screen,
- o Update the displayed pictures immediately after the change of corresponding data in global data base,
- o Accept user key strokes for control panel inputs, and transfers the command to the global data base.

The software is supported by a library of picture elements, e.g., pump, reactor vessel, bar-chart, etc. A picture is constructed by assembling the picture elements in the desired configuration on the graphics display.

Instructor Console Driver module provides executive control, and monitoring capabilities over the Compact Analyzer software operation. The key functions performed through this module include:

- o Initiation, termination or temporary freeze of the simulation process.
- o Model initial condition selection

- o Event, and malfunction (transient simulation) initiation.
- o Alteration of ACSL numerical integration parameters, e.g., max integration step size, communication interval, etc.
- o Snapshot recording of the simulator's states.
- o Continuous monitoring, and override of the data in the global data base.
- o Direct communication with ACSL executive.

The instructor console is menu oriented.

3 NUCLEAR PLANT DEMONSTRATION SYSTEM

For a prototype demonstration system, a Pressurized Water Reactor (PWR) plant model was constructed using EPRI Modular Modeling System. The Analyzer was used for demonstration of an application to plant Emergency Operating Procedures (EOPs) evaluation.

The MMS model presented the Three Miles Island unit 2 (TMI-2) Plant (B&W) NSSS), and included the the primary side, two Once-Through steam generator modules, four reactor coolant pumps, a pressurizer and all connecting piping. On the secondary side, the model consisted of the steam line containing all the steam control valves, low pressure and high pressure turbines, main and auxiliary feedwater chains containing feed pumps, feedwater heater, piping and control valves. The model included a plant control system for the reactor trip, turbine trip, and high pressure injection system. It also contained the reactor coolant inventory and pressure control logic. On the secondary side, the model included the steam generator pressure control logic, main and auxiliary feedwater control systems. All the automatic controls are fitted with manual overrides. The model also included the integrated control system.

The model contains 104 state variables out of which 88 are for the primary side, 10 for BOP and remaining 6 states for the control systems.

The constructed plant model offers good fidelity and can simulate a wide range of steady-state and transient conditions. The model can be used for simulation of operating conditions from zero to rated power provided the primary coolant system remains subcooled. Even with this limitation, it can be used to simulate many of the severe abnormal conditions that may occur during the operation of the plant.

To illustrate the full plant model response, an asymmetric steam line leak is selected for simulation. The initiating event for this transient is a steam leak on Once-Through Steam Generator

(OTSG) A, about 18% of the full power steam flow. This results in excessive primary-to-secondary heat transfer, and consequently a temperature reduction in the reactor coolant system (RCS). To maintain the coolant average temperature, the plant Integrated Control System (ICS) pulls control rods to increase the power. Depending on the initial power level, the reactor may trip on high neutron flux signal. The RCS will continue to cool down and depressurize due to the leak. If the steam leak cannot be isolated, the operator must stop the main and auxiliary feedwater to the affected steam generator to prevent overcooling the reactor coolant system and losing condensate inventory. If the leaking steam generator is not isolated, the excessive overcooling can drain the pressurizer and result in loss of subcooling margin.

The result of the steam leak transient simulation are compared [7] against a reference data provided in the B&W Abnormal Transients Operating Guideline (ATOG) documentation [8] for Rancho Seco plant (Similar in NSSS design to TMI), as shown in Fig. 2. The simulation results have a close agreement, in trends and magnitudes, with the reference data.

Fig. 3 presents one of the user displays developed for the PWR demonstration system

3.1 Illustration Of An Application To EOP Validation

The B&W ATOG identify three main symptoms for abnormal transient conditions:

- o Lack of adequate subcooled margin
- o Lack of primary to secondary heat transfer (overheating)
- o Excessive primary to secondary heat transfer (overcooling)

Recognition of the above main symptoms is facilitated by use of a Reactor Coolant System Pressure - Temperature (P-T) display. By observing the direction of the trace on this display, the above symptoms can be recognized and one can proceed directly to the appropriate section of ATOG to restore plant stability and core cooling. This section will illustrate conceptually how the procedure could be performed using an example accident sequence.

For the asymmetric steam leak transient, the initiating event is the partial loss of steam from one loop. This initiating event is simulated by manually opening the turbine bypass valve associated with Once-Through steam generator (OTSG) of loop A. In the Compact Analyzer this action is initiated through the steam pressure control panel of the simulator console. As the accident simulation progresses, the specific symptoms that are used in the EOP's are displayed on the color graphics CRT.