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MATHEMATICAL AND NUMERICAL MODELS TO ACHIEVE HIGH SPEED WITH SPECIAL-PURPOSE PARALLEL PROCESSORS*

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Historically, safety analyses and plant dynamic simulations have been and still are being carried out by means of detailed FORTRAN codes on expensive mainframe computers in time-consuming batch processing mode. These codes (e.g., TRAC-PF1,[1] TRAC-BD1[2] and RELAP5[3]) have grown to be so expensive to execute that their utilization depends increasingly on the availability of very expensive supercomputers.

Thus, advanced technology for high-speed, low-cost and accurate plant dynamic simulations is very much needed. Ideally, a low-cost facility based on a modern minicomputer can be dedicated to the staff of a power plant, which is easy and convenient to use, and which can simulate realistically plant transients at faster than real-time speeds. Such a simulation capability can enhance safety and plant utilization.

THE BNL PLANT ANALYZER

One such simulation facility that has been developed is the BNL Plant Analyzer,[4,5] currently set up for BWR plant simulations at up to seven times faster than real-time process speeds. The principal hardware components of the BNL Plant Analyzer are two units of special-purpose parallel processors, the AD10 of Applied Dynamics International[6] and a PDP-11/34 host computer.

The AD10 is specifically designed for time-critical system simulations, utilizing the modern parallel processing technology with pipeline architecture. The AD10 consists of six task-specific microprocessors, a multibus, one

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million words of data memory, and versatile input/output channels which accept both analog signals and digital data. The six processors are synchronized at the computing cycle frequency of 10 MHz. Two additions and one multiplication can be carried out in one computing cycle, resulting in 30 million fractional operations per second. With two AD10s working in parallel, the BNL Plant Analyzer has a maximum computing capacity of 60 MFLOP.

The AD10 is programmed by the host computer in the high-level continuous simulation language MPS10 which makes it easy for a programmer to achieve 70% of the maximum computing capacity of the AD10.

ADVANCED MODELING TECHNIQUES

Efficient simulations require an integrated concept which optimizes the formulation of mathematical models, the application of numerical methods, the selection of computer architecture, and the implementation of program instructions. The BNL Plant Analyzer represents a new technology based on such an itegrated concept. The model formulations are based on the following five modeling principles:

1. Principle of Model Selection. Select the least complicated models which accommodate all the available experimental information.
2. Principle of Relevance of Phenomena. Eliminate from the selected models all irrelevant phenomena, while accounting for all important physical processes.
3. Principle of Analytical Solutions. Carry out as many integrations as possible in analytical form, then evaluate the closed-form solutions dynamically during the simulation.

4. Principle of Iterative Loop Elimination. Execute in advance all iterative procedures required for the solution of implicit nonlinear equations and tabulate the results in terms of explicitly known variables, then interpolate the tables during the simulation.
5. Principle of Pretabulated Functions. Combine analytically in every equation all constitutive relations (material properties, empirical correlations) into the smallest possible number of composite expressions, then tabulate the expressions for linear interpolation during the simulation.

Detailed applications of these modeling principles are given in Reference 5.

EFFICIENT INTEGRATION TECHNIQUES

Numerical integration techniques are either implicit, explicit, or a combination of both. Implicit integration involves iterative solutions to transcendental equations. The associated frame time T_i, or the clock time required for advancing the entire simulation from one time level to the next is orders-of-magnitude larger than the frame time T_e associated with the explicit integration.

The permissible integration step size is controlled by accuracy and stability requirements. The rational choice between the explicit and implicit scheme is based on: (i) the frequency f_ν of system stimulants (input data) and system responses (output variables), (ii) the permissible integration step sizes H_i and H_e for implicit and explicit integration, respectively, and (iii) the frame times T_i and T_e.

Figure 1 illustrates the selection of optimum integration algorithms for a variety of system transients. The abscissa represents the relevant frequency f_ν of the system stimulant and response, with the steady state at the left and with extremely rapid transients at the right. The permissible step size H_i for implicit schemes depends on truncation errors which increases with f_ν, causing H_i to decrease with increasing f_ν. The permissible step size H_e for rapid transients is larger than H_i because explicit algorithms are often of higher-order accuracy (e.g., Runge-Kutta methods). However, H_e is limited by the stability limit as indicated by the flat segment of the H_e-curve.

The intersections of T and H curves give the relevant simulation frequencies for real-time computing speeds. Clearly, explicit integration is superior for fast transients, while the implicit scheme is better for slow, near quasi-steady transients. An optimum model formulation can be achieved by eliminating the irrelevant frequency content or numerical stiffness from the model, so that the explicit integration scheme integrates for most transients of interest with the permissible step size lying just below the stability limit.

CONCLUSIONS

Ultra-high simulation speeds can only be achieved by a good match between mathematical models, numerical algorithms, program language and computer architecture. Such a match implies an integrated approach which requires advance planning, careful evaluation and judicious selection of mathematical models, numerical algorithms and computer architecture.

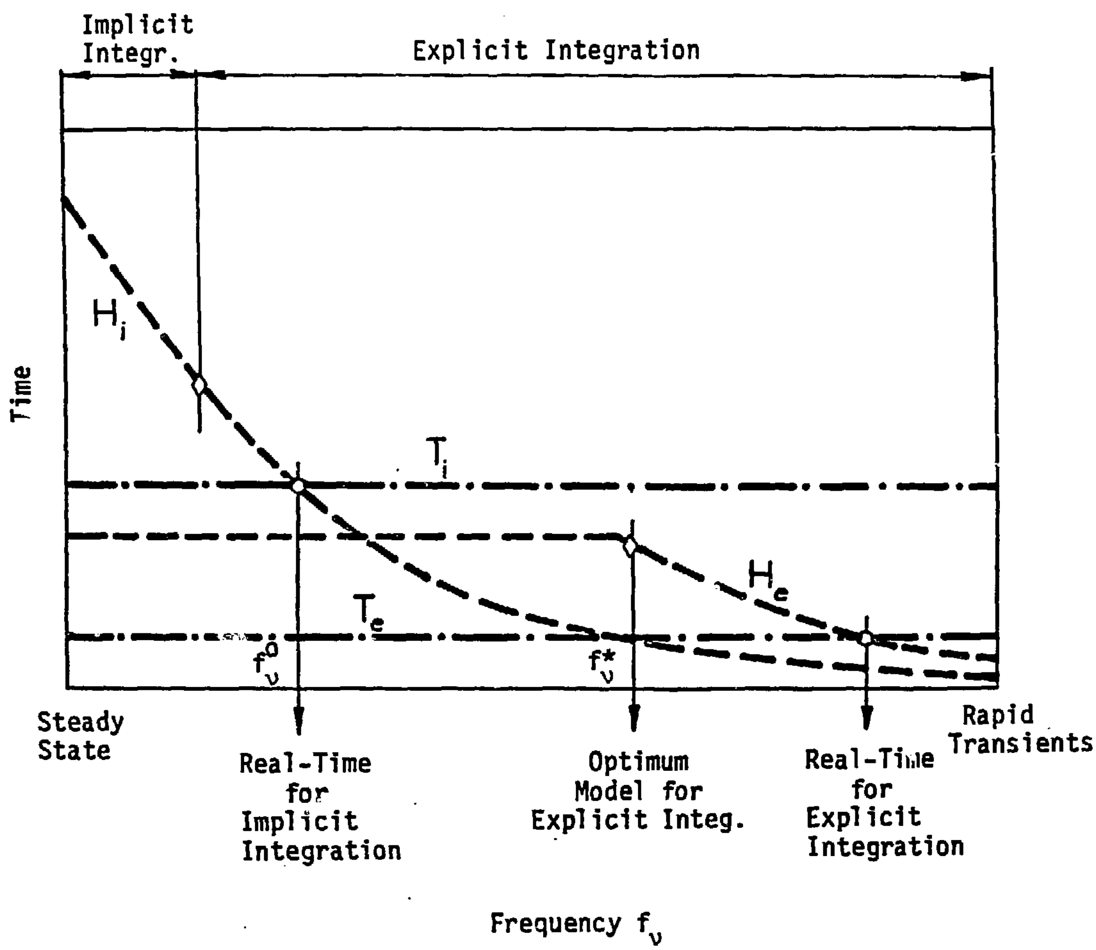

Figure 1 Selection of optimum integration method.
H - permissible time step, t - frame time.

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