MULTIDISCIPLINARY SIMULATION OF POWER ELECTRONICS SYSTEMS

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Abstract

The Virtual Test Bed (VTB) is both a practical user tool for multidisciplinary system simulation and also an environment for exploring and developing new simulation capabilities, and for pushing beyond the existing boundaries of industrial simulation solutions. We provide here an overview of several recent advances in simulation capabilities that have been implemented in the VTB software.

INTRODUCTION

Power electronics systems are strongly multidisciplinary and hence require the support of simulation environments that permit representation of diverse physical processes and equipment. For example, comprehensive performance assessment of a proposed motor drive requires a description not only of the power electronic components but also of the control algorithms, the thermal environment of the power devices, and the dynamic loading imposed by the mechanical system powered by the motor.

But to be really effective, the simulation environment must support far more than just the multidisciplinary aspects of system simulation – it must facilitiate every task of the design engineer. Thus the tool must go well beyond just the desktop simulation capability, to include support for rapid incremental prototyping of the entire system.

For some years now we have been developing a multidisciplinary simulation environment that addresses these problems, and others, under the name Virtual Test Bed. One purpose of this software is to develop new simulation capabilities that push beyond the existing boundaries of industrial simulation requirements and products. Some interesting capabilities that have been prototyped or fully-developed in the software include:

- Power hardware in the loop
- High bandwidth interfaces between power hardware/and digital simulator
- Multirate simulation
- Dynamic reduction/expansion of model order
- mechanisms for cosimulation and other interactions with other software (e.g. Matlab/Simulink)

- Simulation services in support of:
    - control decision-making
    - design optimization
- Geographically distributed simulation
- Management of uncertainty in simulation and control
- Support for industrial design processes – work flow management, version control, etc

We will briefly discuss each of these topics in turn.

SIMULATOR CAPABILITIES

Choice of user-interactive or real-time execution

The early phases of a design project are accomplished at the designer’s desktop where the system is defined, preliminary anlyses are conducted, and the design is iterated until simulation results predict the desired performance. This design iteration is greatly facilitated by a user-interactive environment that allows component values or even whole components to be changed or re-specified on the fly as the simulation runs. During this phase of the design process it is desirable for the simulation to run at the highest possible speed, whether that be faster or slower than clock time.

Later in the design cycle one may wish to run simulations with hardware in the simulation loop. This can be useful to validate one or more of the simulation models by comparing the simulated performance of that part of the system with the measured performance [1] of a prototype. Or it can be used to incrementally build the hardware system by substituting each part into the simulation model as each part becomes available. Either way, a requirement of the simulator is that it run in a hard real-time mode [2].

The process is particularly effective if the same system definition file can be used for desktop and real-time simulation. This is the case for VTB and its real-time counterpart VTB-RT, where the same XML data file serves as input to either environment.

Furthermore VTB-RT is completely based on open source software such as Linux, RTAI (Real Time Application Interface) and Comedi (Library for data acquisition management under the Linux operating system) and off-the-helf hardware.

As result of those implementation choices the migration from the desktop user interactive environment to the real-time hardware interactive environment is extremely smooth and the installation costs are quite small .

High performance computing

Several aspects of the simulator engine are designed to achieve the high simulation speeds that are beneficial during the design process. Distributing the simulation across multiple processors on a single computer, across multiple computers on a network, or across multiple geographic sites of a corporate facility are all beneficial in various ways. A current implementation of the VTB solver permits the system to be solved in a multiprocessor environment, although the immediate implementation requires that the system be partitioned at points of weak coupling where signal-flow coupling, rather than natural coupling, can be used. Future implementations of the solver will permit distributed simulation of naturally-coupled systems.

Power hardware in the loop

In effect, the concept of incremental prototyping involves not only incremental methods for definition of models of newly-conceived equipment, but also methods for incremental substitution of real equipment into the simulation model. To support this process we have developed techniques that we refer to as “power hardware in the loop.” Or PHIL [4][5][6]. The terminology specifically distinguishes these techniques from the more usual “hardware in the loop” [3] situation which involves only the exchange of signal quantities at the point of connection between the hardware and the simulation model, rather than the exchange of virtually conserved quantities such as charge or mass. Thus, power hardware in the loop necessarily involves both a transducer and a mechanism for ensuring self-consistency between the across and through variables (e.g. voltage and current for electrical systems) at each end of the connection.

High bandwidth interfaces

Simulation with power hardware in the loop requires wide bandwidth interfaces between the simulation model and the power hardware [7]. But more than just speed, the interface often must be conceived as part of a multi-rate simulation environment. This is especially true when dealing with power electronics systems in which it may be necessary to exchange gate drive signals or encoder signals at very high speeds compared to the time step for simulation of the other parts of the system. We have developed methods both for using FPGAs both for interpolation and for averaging of the exchanged quantities in order to match the needed data exchange rates on both sides of the system partition [8].

Multirate simulation

Power electronics systems almost invariably contain components having widely disparate time constants. The switching action of a power converter might occur at 100’s of kilohertz, requiring time resolution of the switch dynamics in the sub-microsecond range, while portions of the power system operate with relatively smooth dynamics at 60 Hz, (perhaps millisecond time resolution is satisfactory), and mechanical or thermal parts of the system may only require time resolutions on the order seconds. Simulation models of these different parts of the system can be stepped at different rates as long as methods for reconciliation of the natural conservation laws and causality are followed. The first implementation of a multi-rate solver for the VTB has been completed, although it currenly allows decomposition of the system only along signal flow paths. A next implementation will allow the user to specify the point(s) of system decoupling at natural nodes, and yet further implementations will perform that decomposition automatically.

Dynamic reduction/expansion of model order

One must often trade model accuracy for model execution speed, or vice versa. One compromise is to change the representation of the model (the model order, or essentially the number of system states or dynamic equations) in response to the current operating point of the model. We have developed methods for doing that for a few specific models. In those cases, simulation speed was typically increased by a factor of 2, while model accuracy decreased by only one percent when compared to running the simulation with only the high-resolution model [9],[10].

Cosimulation

No existing simulation environment meets all users requirements or preferences, hence it is desirable to allow simulators to work co-operatively. The VTB provides methods and wrappers that permit other engines, such as Matlab/Simulink, to cosimulate. This is especially useful when using Simulink, the defacto standard in control design, to define a control system and then connecting that control to a power electronics network that must satisfy natural conservation laws and that one wishes to define by the topology of the hardware, rather than by the topology of the descriptive equations. [11][12].

Simulation services

There are many instances in which another tool wishes to employ simulation services to accomplish the primary tool's tasks. Two concrete examples: design optimization and model-based predictive control. In both cases the objective of the primary tool is to use a simulator to execute a series of "what if" scenarios and then to choose the result that gives the best performance. In design optimization, an algorithm (e.g. genetic algorithm, max/min, etc.) may specify a set of parameters to try and the purpose of the simulator is to compute how the system will perform for each set of parameters. The primary tool evaluates the effect of the parameter change and then causes the parameters to evolve in a direction that improves some aspect of the system performance. The control application is similar, allowing the primary application to suggest possible control actions, then allowing the simulator to describe how the system would perform if that control action were taken. The VTB simulator supports use of the solver engine in this mode via ActiveX.

VTB is equipped with a full Application Program Interface that allows any other program that adheres to the ActiveX standard to use VTB a simulation server. Thusan external software can open a particular schematic, change parameter values, request simulation output, and advance the simulation engine in a step by step mode [13].

Management of uncertainty

Virtually all simulators describe the performance of a completely-specified system. But at the same time there is often very little certainty about the parameters of a particular physical system. And especially there is little certainty about the parameters of a set of physical systems. The usual method for dealing with this uncertainty is to compute the response of the system for a discrete set of cases chosen by a Monte Carlo method. An alternative approach based on Polynomial Chaos Theory (PCT) has been implemented in one version of the VTB solver. The alternative approach has several advantages. Foremost among them is that the distribution of system responses is computed as time progresses, rather than sequentially in time like in a Monte Carlo method, so that the simulation model can be changed on-the-fly (i.e. it can support design iteration or hardware in the simulation loop). Furthermore the PCT is able to reconstruct the full probability density function (PDF) of a variable in a single simulation run. The PDF is also known analytically so that further analysis on the statistics can be performed with higher accuracy than by using a Monte Carlo approach [14][15].

Support for workflow processes

System designers in industry rely on a set of procedures or work-flow processes to ensure the integrity and completeness of a product design. These workflow processes should be at least enabled or facilitated by the tool, if not built directly into the tool. The VTB provides a number of mechanism for managing workflow during the system design process. These range from methods for incremental definition of system components and models of those components, to the definition and assignment of roles, role-associated permissions, and credentials for individual users, and for user groups. The tool also provides mechanisms to decompose a system into subsystems and to define connectors between the subsystems so tha the system can be re-composed at simulation runtime. Methods for maintaining source control by using a single database, and to automatically notify co-designers of design changes are built in.

Geographically distributed simulation

It is increasingly common that the co-developers of a system work at geographically-dispersed sites belonging to one or more companies. In some cases, it is desirable or even essential to maintain control of intellectual property within the site boundaries. This motivates the use of geographically distributed simulation. In contrast to local-area simulation, where timing of distributed simulators is relatively straightforward, geographically-distributed simulation requires new methods for ensuring the identity of simulation time. In the VTB, this can be ensured by the application of GPS-based clock generators that maintain a common simulation time [16].

CONCLUSIONS

We have presented a quick overview of some aspects of the Virtual Test Bed software which is a unique environment for performing multidisciplinary simulations and for exploring and advancing the state of simulation softare. The environment is noteworthy for its flexibility, adapability, and capability. One or more versions are freely available for download from the project web site[17]. Also, a commercial version named VTBPro will soon be released under license from the University..

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