APPLICATION OF HARDWARE-IN-THE-LOOP FOR VIRTUAL POWER PLANT

Tomasz BARSZCZ, Michał MAŃKA

Departament of Robotics and Mechatronics, AGH University of Science and Technology,
Al. Mickiewicza 30, 30-059 Cracow, fax: (012) 634-35-05, email: tbarszcz@energocontrol.pl,
mmanka@agh.edu.pl

Summary

The following paper presents application of the Hardware In The Loop to the Virtual Power Plant laboratory(VPP), for real time modeling of power generation unit elements. The Virtual Power Plant consists of a group of computers, which model a real power plant unit with the performance close to the real time. Application of HIL enables the laboratory to generate output signals which can be used for testing of monitoring systems or by using exciters for testing of vibration sensors i.e.: accelerometers. The paper presents implementation process of chosen module of VPP on dedicated system for real-time simulation based on DS 1103 board. Next an experimental results are discussed.

Keywords: simulation, hardware-in-the-loop, power plant, real time simulations.

ZASTOSOWANIE TECHNOLOGII HARDWARE-IN-THE-LOOP
W PROJEKCIE WIRTUALNEJ ELEKTROWNI

Streszczenie

W pracy przedstawione zostało zastosowanie technologii Hardware-In-the-Loop (HIL) projekcie Wirtualnej Elektrowni (VPP) do modelowania działania elementów elektrowni w czasie rzeczywistym. Wirtualna Elektrownia składa się z grupy komputerów które modelują działanie rzeczywistej elektrowni z wydajnością bliską czasowi rzeczywistemu. Zastosowanie technologii HIL pozwoli na generowanie w laboratorium sygnałów wyjściowych z VPP które mogą zostać wykorzystane np.: do testowania układów monitorowania bądź też, po zastosowaniu wzbudników, do testowania czujników drgań np.: akcelerometrów. Artykuł przedstawia proces implementacji wybranego modułu VPP na dedykowany układ do przeprowadzania symulacji z rygorem czasu rzeczywistego oparty na karcie DS 1103. Następnie omówione zostały uzyskane wyniki badań eksperymentalnych.

Słowa kluczowe: symulacja, Hardware-In-the-Loop, elektrownia, symulacje czasu rzeczywistego.

1. VIRTUAL POWER PLANT AND ITS ARCHITECTURE

Advances in condition monitoring, and – in the broader view – in mechanical engineering lead to the development of more and more efficient tools, which help us to better understand behavior of mechanical systems [1, 2]. Then, we can benefit from this knowledge by optimization of operation and reduction of maintenance costs, to name just a few [3]. Recently, the Virtual Power Plant laboratory (VPP) was developed within the research project DIADYN No PBZ-KBN-105/T10/2003, funded by the Polish Ministry of Science (MNiI).

VPP is the innovative work environment for technical state assessment of dynamic objects, applied to elements of the power plant unit. Such an environment should work with performance close to the real time (when necessary and technically possible). Introduction of such an environment facilitates development of models and next – the process of diagnostics. Such an environment has following benefits:

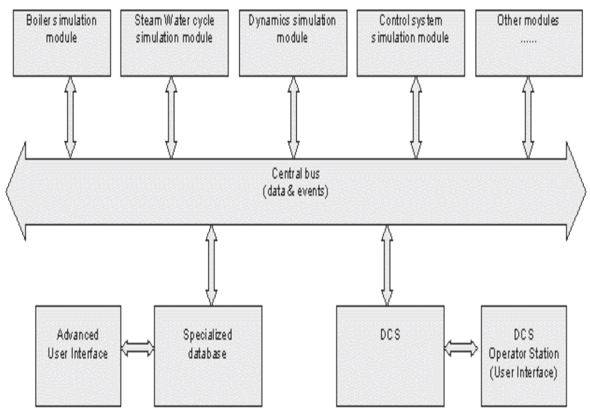

Fig. 1. The structure of the Virtual Power Plant

- flexible structure, enabling multiple configurations;
- possibility to include models in various formats (though Matlab/Simulink was chosen as the default);

- reply of malfunctions to analyze real cases from the plant;
- modeling of faulty behavior of a plant to improve the knowledge about processes in the real plant
- simulation of various modifications of the unit and effects it will have, for example in the dynamic state;
- huge resource for search of diagnostic rules, thus it will bring advances in FDI techniques;
- development of risk management algorithms;
- verification of diagnostic systems in operation on a plant.

The Virtual Power Plant [4] is the group of computers, connected by a fast computer network (see Fig. 1). Each computer plays a role of a VPP component. The largest part of the system is database, which consists of two cooperating subsystems. The first one is the database as in the typical DCS system. This allows to store the data in the same way they are stored in a real system. The second database subsystem is a specialized, fast database which is used to store data generated by modules of the VPP. This subsystem is proprietary, efficient database engine, which can also store dynamic data (e.g. vibration waveforms). The Central Bus is another computer, which is the main data exchange hub in the VPP. It provides common interface for all the modules, which allows to develop each module independent from the others. The remaining computers are used to run models of the components of the power plant. Fig. 2 presents the structure of the VPP model. The mathematical model used in the Virtual Power Plant is a compromise between the requirements of the accuracy to the real object and available computing and data processing power [5]. On the other hand, its structure allows for easy exchange of several components, depending on requirements of the application.

As presented on the Fig. 2, modeling of the dynamic state is weakly coupled with the rest of the model. There are no feedbacks and there is only one signal determining the vibration, i.e. rotational speed. Since on the list of applications presented above, the important one is verification of vibration monitoring and diagnostic systems (VMDS) in operation on a plant, there was a need to generate real-time vibration signals, which could be converted to analogue signals and fed into a vibration monitoring system. With proposed approach, it would be possible to test VMDS in various conditions, also impossible to simulate on a real power generation unit. Since the model was developed as the variable step Matlab/Simulink model, it did not generate such signals and other real time simulation techniques were necessary.

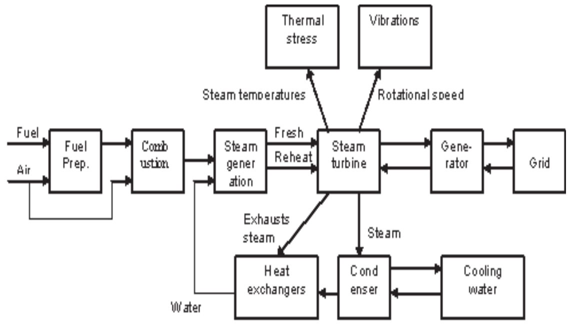

Fig. 2. The structure of the model

2. REAL TIME SIMULATIONS

Real-time system can be divided into two main categories:

- Hard real-time system - where timing correctness is critical for the system and can't be sacrificed for other benefits.
- Soft real-time systems – where time correctness is important, but not critical and can be sacrificed for other goals (for example model accuracy).

Typical real-time system consists of two parts: controller and controlled system. Depending of structure of these two parts real-time simulations can be divided into :

- Rapid prototyping of control systems;
- Hardware-In-The-Loop.

Nowadays there are two major systems used for real-time simulations:

- Systems based on FPGA systems – used mostly for fast prototyping;
- Systems based on DSP cards – used equally for fast prototyping and HIL simulations.

The system presented in the paper is based on the second solution for real-time simulations. dSPACE is one of the providers of real-time systems based on DSP's. They provide vide variety of systems designed for fast prototyping and HIL simulations. Systems offered by dSPACE varies from simple single board (DS 11xx series) to multi-board systems (dSPACE Simulator). Single board system consists of single card with processor, memory and additional input/outputs (ex.: D/A, A/D converters, DIO's, Encoder inputs). Multi-boards system consists of dedicated processor board(s – up to 20) and dedicated I/O cards connected via PHS bus. dSPACE also provides a software as a part of its system. It can be divide into 3 groups:

- Card's drivers for C/C++;
- Implementation software allows for connecting created model to dSPACE I/O boards;
- Test & Experiment Software'.

The system used during presented experiments is built using dSPACE real-time environment, based on the dSPACE's DS1103 board .

3. SYSTEM IMPLEMENTATION

Careful analysis shows, that first part of the VPP, which should be tested on real-time system is Vibration Module, as explained in the first chapter. Vibration signals, generated in real time, can be easily sent as outputs via digital outputs or D/A converters and used for example as an inputs for monitoring system or as control signal of exciter used for testing i.e.: accelerometers.

The first step in implementing Vibration Module of VPP on the real-time system was re-writing of s-function written as m-file into C-code ones. Currently, dSPACE's software doesn't support direct translation of m-file into real-time C-code that can be implemented on dedicated board. Other requirements of dSPACE's real-time system is that the simulations have to be performed with fix step. It can be obtained in two ways: translating s-function from variable step into fix step type, or by solving continuous states with chosen integration method (i.e.: Euler, Heun, Bogacki-Saphine, Runge-Knutt, Domand-Prince).

Because in C-code all variables (types, size of matrixes etc.) should be declared and defined before compilation, single 5-mode model of rotor-support was chosen for implementation. During translating m-file into C-code, algorithms were not only rewritten in C-code, but also optimized for faster calculations. Moreover, standard C-libraries does not consist matrix class variables nor matrix operation definition (addition, subtraction, multiplication and division of matrices). This is why dedicated libraries for matrix operations have been created.

After creating VPP's Vibration Module as C-code's s-function Matlab/Simulink model was built and simulated. Simulations results obtained from m-file and C-code models were compared and proved that translation process was successful (fig. 3).

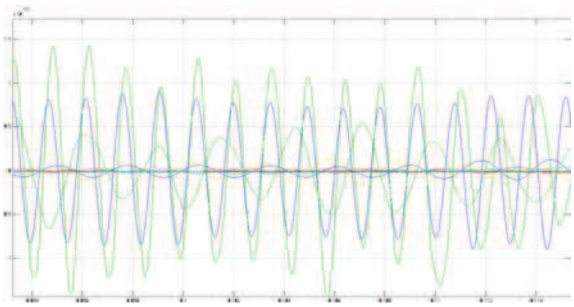

Fig. 3. Differences between vibration signals obtained from the vibration module of VPP written as M-function and in C-code

Next, created model were compiled with RTI (Real Time Interface) for the real-time system. The RTI runs through all steps necessary to prepare the application for the real-time test. The last step loads the application into the dSPACE processor. The RTW (Real Time Workshop) is used for converting Simulink's models into real-time C-code and automatically builds programs, that can be run from the real-time system environment. ControlDesk software – experiment software for managing and instrumenting experiments – is the integral part of dSPACE's real-time system,. It allows for designing experiment interfaces by easy drag & drop method. The interface designed for Vibration Module is presented in the figure 4.

The interface allows for real-time observation of simulated vibrations and changing parameters of simulations. Compiled model consists of four different types of rotor-support models (sliding bearing, nonlinear heuristic, short bearing and long bearing) and two parameters (Gravity and Damping) that can be changed using radio buttons during experiments without the need of simulation interrupting. Several experiments were performed for all four models with and without influences of gravity and damping.

First tests taken on real-time system were carried out at step size set to 0.01s , and shows that at that step size created models are unstable. Reduction of the step size allowed to achieve stable results at value 0.001 s, but good results, similar to ones obtained during simulations with variable step, were achieved at step size of 0.0002 s.

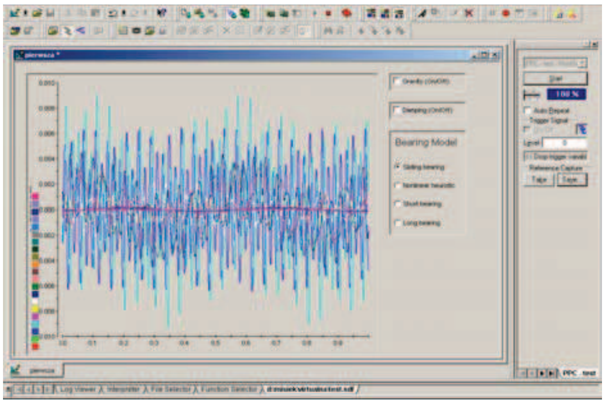

Fig. 4. Experiment interface

At this step size, the equipment used during experiments (DS 1103 board) allows only for simplest model (sliding bearing) simulation. Obtained results (fig. 5) were very similar to ones obtained from Matlab/Simulink with m-file variable step model (fig. 6), (amplitudes, phases of vibrations). Unfortunately, higher frequencies of simulated signals were cut off, due to insufficient frequency.

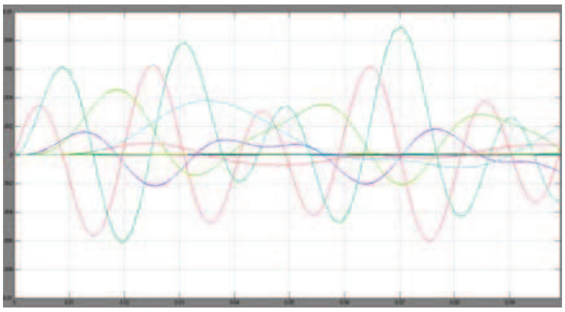

Fig. 5. Results obtained during HIL simulations

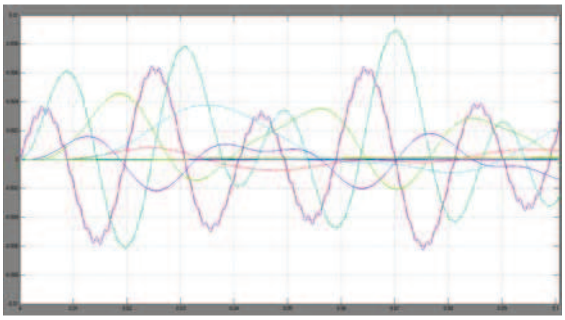

Fig. 6. Results obtained during Simulink's simulations

4. CONCLUSIONS

Application of Hardware-In-the-Loop technique for simulation of Vibration Module of the Virtual Power Plant showed promising results. It can lead to much broader application of VPP. Initial experiments proved that optimized code can lead to significant performance improvement (step size from 0.01 up to 0.0002 s). Unfortunately hardware restriction didn't allow to achieve results, which fully represent vibrations in given rotor-support model. Theoretical analysis and initial experiments proved that after equipment upgrade (change of real-time simulation system to multi-board system based on DS 1006 processor board) new hardware should provide sufficient computational power for real-time simulations of complex model.

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Tomasz BARSZCZ, Ph D.
Employed at Dept. of Robotics and Mechatronics, on AGH Univ. of Science and Technology, Cracow, Poland. His main field of research is design and applications of systems for machinery monitoring and diagnostics. He is author of two books, numerous papers and applications in this field.

Michał MAŃKA, Ph D.
Employed at Departament of Robotics and Mechatronics, on "AGH" University of Science and Technology, Cracow, Poland. He is the author of numerous publications concerning active balancing of rotating machineries, mechatronic design and real-time simulations.