FPGA-based simulation models for highly dynamic controlled systems

Things Are Speeding Up

In demanding and highly dynamic electromobility applications, FPGAs provide an enormous performance boost for real-time simulation. dSPACE is moving one step closer to the future by providing completely FPGA-based simulation models.

In hardware-in-the-loop (HIL) simulation, field-programmable gate arrays (FPGAs) are typically used to take some of the load off the processor. Particularly time-critical I/O computations are performed on the FPGA so that the processor has more capacity to calculate the plant model. However, this procedure is useful only if the models are not too complex and the sampling rates are not too high. When controllers are developed for the dynamic, highly precise ECUs installed in electric vehicles, the procedure sometimes reaches its limits. The solution is to compute not only the I/O but also the entire plant model on the FPGA. dSPACE now provides a library of ready-to-use components for this (figure 1).

For Highest Dynamics Requirements

In conventional approaches, processors frequently have only enough computing power to simulate mean-value models, often updating the output signals only once per PWM cycle.
When the highest demands are made on dynamics and signal precision, FPGA-based model computation offers decisive advantages. FPGAs reach very high sampling rates that allow output signals to be updated considerably more often than once per PWM cycle. This ensures a far greater simulation quality (figure 3). For example, with high-frequency simulation it is possible to simulate the inductance current ripple caused by PWM control, simulate higher frequencies with greater precision, and ensure high control loop stability. In comparison with a processor-based model, cycle times are typically reduced from 50 µs to 100 ns.

Convenient Model Library

For maximum convenience in creating FPGA-based models, dSPACE offers a library of completely modeled electrical components: the XSG Electric Components Library. This library is available during work in Simulink®. The models were created with the Xilinx® System Generator (XSG) blockset. During code generation, they are directly converted to VHDL code that is executable on an FPGA such as the DS5203 FPGA Board. The generation of interfaces is partly automated so that in many projects, developers do not require detailed knowledge of FPGA programming, just experience in using Simulink.
The FPGA library contains ready-made models for the following components:

- Permanent magnet synchronous motor
- Brushless direct current motor
- Direct current motor
- Three-phase frequency converter
- Incremental encoder
  - Resolvers
  - Sine encoder
  - TLL encoder
  - Hall encoder
- Aids
  - Mean-value calculation
  - Tables: 1-D, 2-D
  - Scope function
  - Center-aligned PWM measurement

The Advantages of FPGA-Based Simulation

The FPGA-based models from dSPACE also have other advantages in addition to very fast computing speeds:

- *Project-specific adaptations:* The models are open and their implementation can be viewed right down to base block level. So users can either make project-specific adaptations themselves, or have them implemented by dSPACE Engineering Services. They can therefore react flexibly to sudden project or requirement changes.

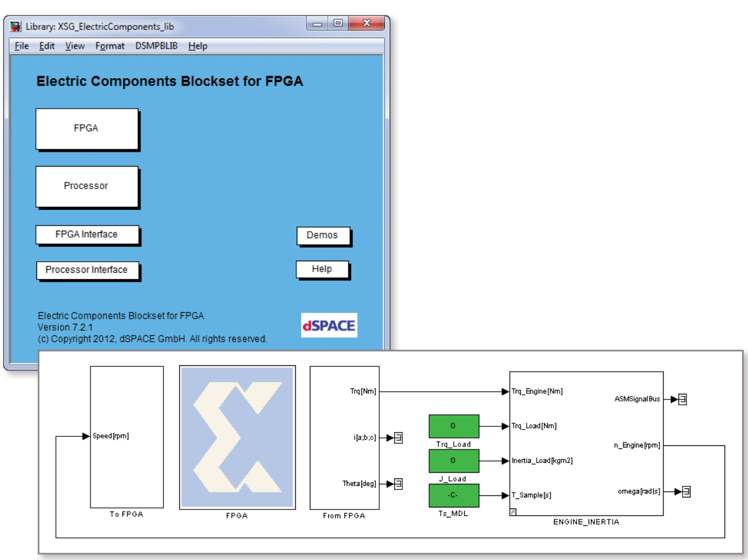

Figure 1: The XSG Electric Components Library contains ready-to-use model components.

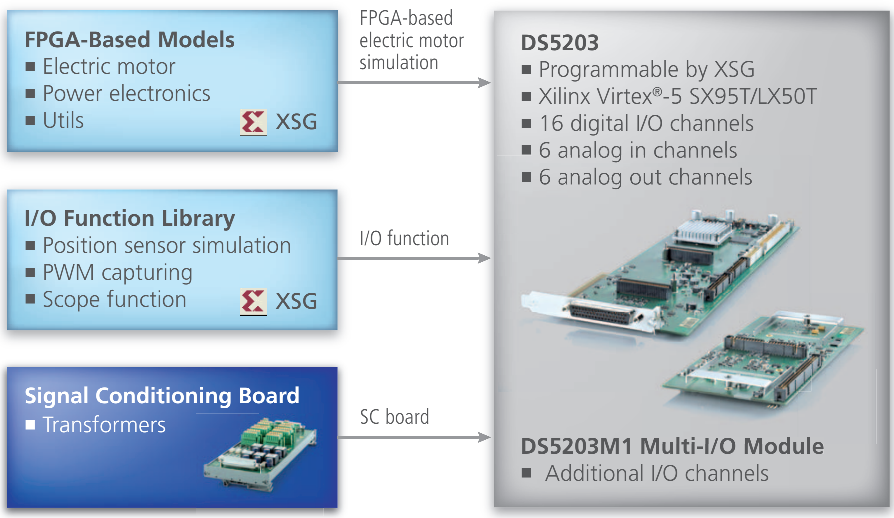

Figure 2: FPGA-based simulation uses the FPGA simulation models and the DS5203 FPGA Board, together with additional modules if required.

- *Extensions to model components:* Because the models are open, users can not only adapt them freely but also extend them by adding their own specific model components.
- *Offline and online simulation:* Function development on a PC is supported by offline simulation. The same model and the same parameterization can be used seam-lessly throughout all the phases of devel-opment. It is easy to reuse tests and compare the simulation results from different phases.

Know-how from Practical Experience

To make sure the FPGA library is intuitive and easy to use, dSPACE incorporated their experience from numerous customer projects into it. The I/O functions were created along the same lines as the functions for the dSPACE EMH Solution, a special I/O board for the HIL simulation of electric motors. This was also based on dSPACE's experience from numerous customer projects.
The models are designed so that systems such as the highly dynamic electric motor model and the resolver model can run in parallel on the FPGA. Via an RTI interface, they communicate with a slower mechanical model running on the processor board.

Powerful Combination of Hardware and Software

The new FPGA library is ideal for use in conjunction with the freely programmable DS5203 FPGA Board. Users can implement complete model components from the library on the FPGA, for example, a permanent magnet synchronous motor model including a resolver model. The FPGA model is integrated into an overall model that runs on the processor board. The necessary interfaces are created automatically.
The connection between the dSPACE hardware and Simulink runs as usual via a Real-Time Interface (RTI) blockset. The DS5203 can be extended by plug-on I/O modules such as the DS5203M1, which doubles the number of channels. Other special modules support tasks such as the signal conditioning required for simulating electric motors, including transformers for resolver simulation.

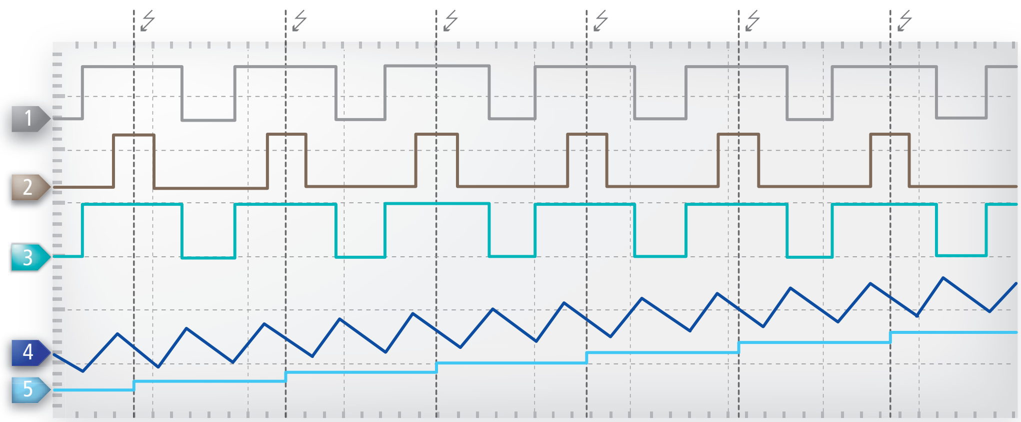

Figure 3: A comparison of the signal quality achieved with processor-based and with FPGA-based models.

Application Examples

The typical application areas for the XSG Electric Components Library are HIL simulations of highly dynamic controlled systems in the field of electric drives technology. Combining fast model computation and low I/O latencies provides benefits that enable these tough challenges to be met:

- Realistic representation of current behavior, as required for developing analog current controllers, with a sampling rate considerably higher than once per PWM period.
- Simulating electrical circuit frequencies higher than 1000 Hz takes processor-based simulations up against their limits. Using FPGA technology increases the range several times over. The computation is 500 times faster with an FPGA-based model.
- Highly dynamic applications such as DCDC converters require higher PWM frequencies. These frequencies are higher than 20 kHz, and the current and voltage can be represented realistically only by means of FPGA-based simulation.
- When an electric motor is simulated at power level, voltage and current values must be represented as realistically as possible. This is necessary if these reference values are to be used as input to the electronic load. Here too, fast computation is absolutely essential.

Conclusion

- Ready-made components for convenient creation of FPGA-based models
- Fast, project-specific model adaptation
- Online and offline simulation
- FPGA-based simulation provides much greater realism than processor-based simulation.