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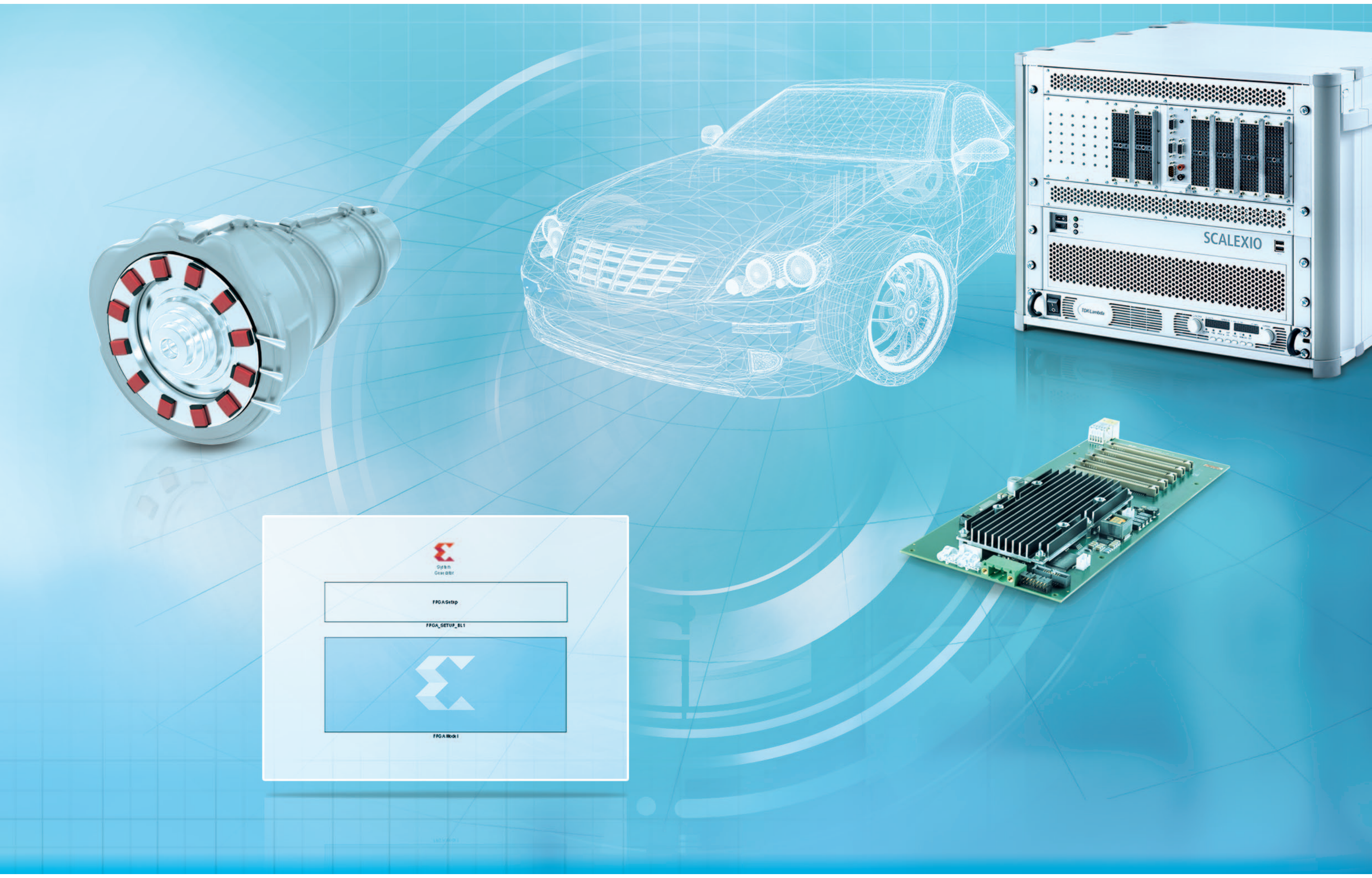

HIL Tests for Automotive Power Electronics

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The development of sophisticated automotive power electronics requires a flexible hard-ware-in-the-loop test system with powerful FPGA technology connected to the real-time processor. The system must also provide a convenient library for modeling electrical compo-nents. To meet the challenges of the future, dSPACE has developed SCALEXIO®, a powerful and flexible HIL simulator with cutting-edge FPGA technology.

Particularly when electric drives are simulated, there are scenarios that require the simulta-neous computa-tion of complex simulation models and highly precise measurement of the electronic control unit (ECU) sig-nals. Generally, time-critical I/O com-putations are described by an FPGA model. Even parts of the plant model are frequently executed on the FPGA to meet the needs of a modern ECU. dSPACE's SCALEXIO provides a conve-nient solution for both these cases and also for mixed scenarios. If mean value models are used on the proces-sor side, the output signal is often updated only once per ECU control step size (typically 50 µs). FPGA-based model computation offers decisive advantages for highest requirements on dynamics and accuracy. FPGAs reach very high sampling rates so that output signals are calculated and updated consider-ably more often than once per ECU sampling cycle. The re-sult is an ap-preciably higher quality of simulation. For example, high-frequency simula-tion makes it possible to simulate the inductance current ripple caused by PWM control, improve the precision with which higher frequencies are simulated, and ensure high control loop sta-bility. The measurable latency between the hardware input and hard-ware output is typically reduced from 50 µs to about 1 µs in comparison to processor-based models. The simulated current values are output every 100 ns.

Tests at the Power and Signal Levels

In HIL simulations of electric drives, a distinction is made between the power level and the signal level. If it is possible to test the ECU's control function at signal level, the cost-intensive part of the power electronics can be omitted. If the tests have to include the power stages, or if it is not possible to separate the control part and the power part, simulation has to be performed at the power interface. Therefore the real electric currents and voltages at the connection terminals of the inverter stage have to be emulated. Generally, emulating real currents and voltages requires a real-time processing system with appropriate hardware interfaces and a model for electronic loads.

Controlling the electronic loads requires the highest possible update rates, so computation on an FPGA is essential.

Powerful Combination of Hardware and Software

Very short cycle times can be achieved by computing the plant model on an FPGA. The mod-els are based on the Xilinx® System Generator (XSG), a Simulink® blockset optimized for Xil-inx FPGAs. Users can perform project-specific modifications them-selves, and react promptly and flexibly when changes are made to the proj-ect or requirements. Moreover, they can also extend or optimize the open models to incorporate their own ideas. The Simulink interface to the hardware is provided by the RTI FPGA Program-ming Blockset and Configura-tionDesk:

- On the processor side, Configura-tionDesk® connects the application to the FPGA model, which is ex-ecuted on the DS2655 FPGA Base Board.
- On the FPGA side, the RTI FPGA Programming Blockset connects the XSG model to the processor model and provides access to the I/O of the connected I/O modules.

In addition to the RTI FPGA Pro-gramming Blockset, dSPACE also provides libraries for model-ing FPGA applications. The model libraries are open, so users can always view them in detail right down to the level of basic blocks. One important library is the XSG Electric Components Library (Figure 1). It contains FPGA models of components such as a permanent magnet syn-chronous motor, several different DC motors, and various incre-mental encoders. In addition the library provides numerous auxiliary function

Figure 1: The XSG Electric Components Library contains ready-to-use model components.
FPGA-based simulation uses the FPGA simulation models and the DS2655 FPGA Base Board with up to 5 I/O modules.

blocks such as mean value computa-tion, set of characteristic curves, and center-aligned PWM measurement. The XSG Electric Compo-nents Library also provides a high level of conve-nience so that specialist knowledge in FPGA programming is unneces-sary. Only some experience in using Simulink, as well as hardware-oriented thinking is needed. Handling is simple because the generation of the RTI FPGA Pro-gramming Blockset interface is partly automated. During code genera-tion, the XSG-based FPGA models are converted directly into HDL code that can run on the FPGA of the dSPACE DS2655 FPGA Base Board.

Small Model Step Sizes with High Bandwidth

If only a submodel is to be calcu-lated on the FPGA, or if the FPGA board is used only as an I/O board with special I/O functions, very close coupling with the processor model is usually necessary. In such cases, the plant model for the power electronics has to run with at least the step size of the ECU. Because it is not practi-cally possible to implement model computa-tion at 10 times the speed of the ECU, but only at twice the speed (i.e., less than 25 µs), the model must also run synchronously with the ECU. The ECU's clock can be recovered on the FPGA by using the XSG Electric Components Library.

Extensive system setups can easily have an extremely large number of I/O channels, so a low-latency, high-bandwidth (up to 100 MB/s) con-nection between the FPGA and the pro-cessor is needed. The I/O signals also have to be updated on the ECU according to the speci-fied model step size. Only extremely powerful HIL net-work technology can fulfill these pre-conditions. SCALEXIO and the network technology developed especially for it, IOCNET, meet these requirements for bandwidth and model step size and even leave room for more.

Know-how and Practical Experience

Over the last few years especially, it has become increasingly important that the HIL simula-tor processes the growing I/O data volume in accordance with real-time and does not re-duce the processor time for model computation too much. SCALEXIO was therefore designed so that the I/O signals are preprocessed decentrally on the boards and connected to the pro-cessor via the specially developed high-end network technology IOCNET.

The XSG Electric Components Library owes its easy and intuitive usability to years of experi-ence with 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. They communicate with the slower mechani-cal model running on the processor by means of blocks from the RTI FPGA Programming Blockset.

Application Examples

A combination of fast model com-putations and low I/O latencies is indispensable for simulat-ing highly dynamic controlled system in electric drives engineering, and is also a typical ap-plication area for SCALEXIO. With the connection to the XSG Electric Components Library, the following challenges can be handled:

The realistic representation of cur-rent behavior required for developing analog current con-trollers runs with a sampling rate considerably higher than once per PWM period. Simulat-ing electrical circuit with frequencies higher than 1 kHz, processor-based simulations exceed their limits. Using FPGA technology increases the range several times over. The enormous FPGA sampling rate makes PWM synchroni-zation unnecessary, so now systems with a variable PWM switch frequency can also be simulated realistically.

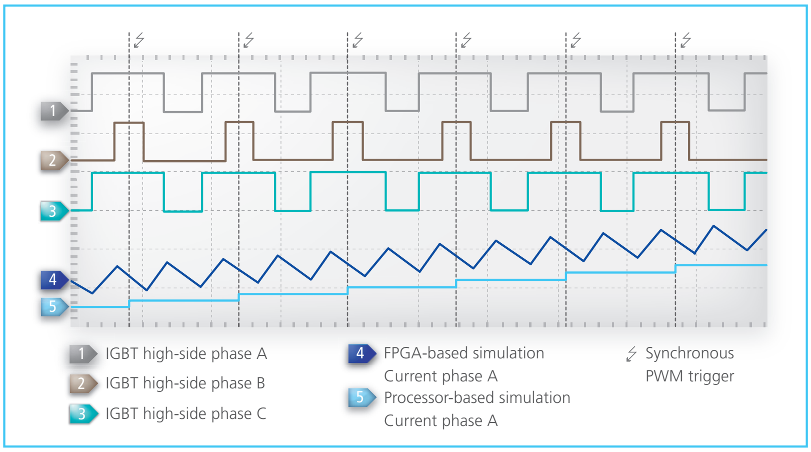

Figure 2: A comparison of the signal quality achieved with processor-based and with FPGA-based models.

Highly dynamic applications such as DC/DC converters require higher PWM frequencies. These frequencies are higher than 20 kHz, and the only way to represent the current and voltage realistically is by FPGA-based simulation. When an electric motor is simulated at power level, voltage and current values must be represented as realistically as possible (Figure 2). This is necessary if these reference values are to be used as input to the electronic load. Here too, fast computation on the FPGA is absolutely essential.

Conclusion

With SCALEXIO, the freely programmable DS2655 FPGA Base Board and the XSG Electric Components Library, users can very conveniently integrate simulation models on an FPGA and connect them to the processor to achieve very high performance. This enables users to create applications that directly access the DS2655 board's I/O with virtually no latencies, and to utilize the entire bandwidth of the signal converters. Control loops can therefore be closed with very short cycle times to allow the simulation of highly dynamic systems.

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