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WHITE PAPER

Accurate Modeling for Robust Simulation of Power Electronic Systems

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Overview

Power electronic systems play a critical role in the modern electrified world. These systems require robust design to ensure safety and reliability under all operating conditions. Examples include automotive, aerospace, energy generation, and industrial systems. Optimizing power electronic systems for these applications requires accurate modeling and advanced simulation capabilities long before construction of physical prototypes. Traditional approaches and basic circuit simulation are no longer adequate for rapid exploration of architecture options early in the design process or for handling large, complex power electronic system designs. This white paper presents a comprehensive solution to fill these gaps and discusses how to model the systems for accurate results.

Introduction to Power Electronic Systems

Nearly everything everywhere is electrified in today's world. Electrical power generation and distribution is at the heart of modern civilization. The backbone of the electrical infrastructure uses electric and electro-mechanical devices such as generators, motors, transformers, and switches. These are well understood and proven in daily use since the days of Thomas Edison and Nikola Tesla. However, modern requirements add complex systems to this infrastructure that control electric power in many ways, with semiconductor devices central to the designs. This is the domain of power electronic systems.

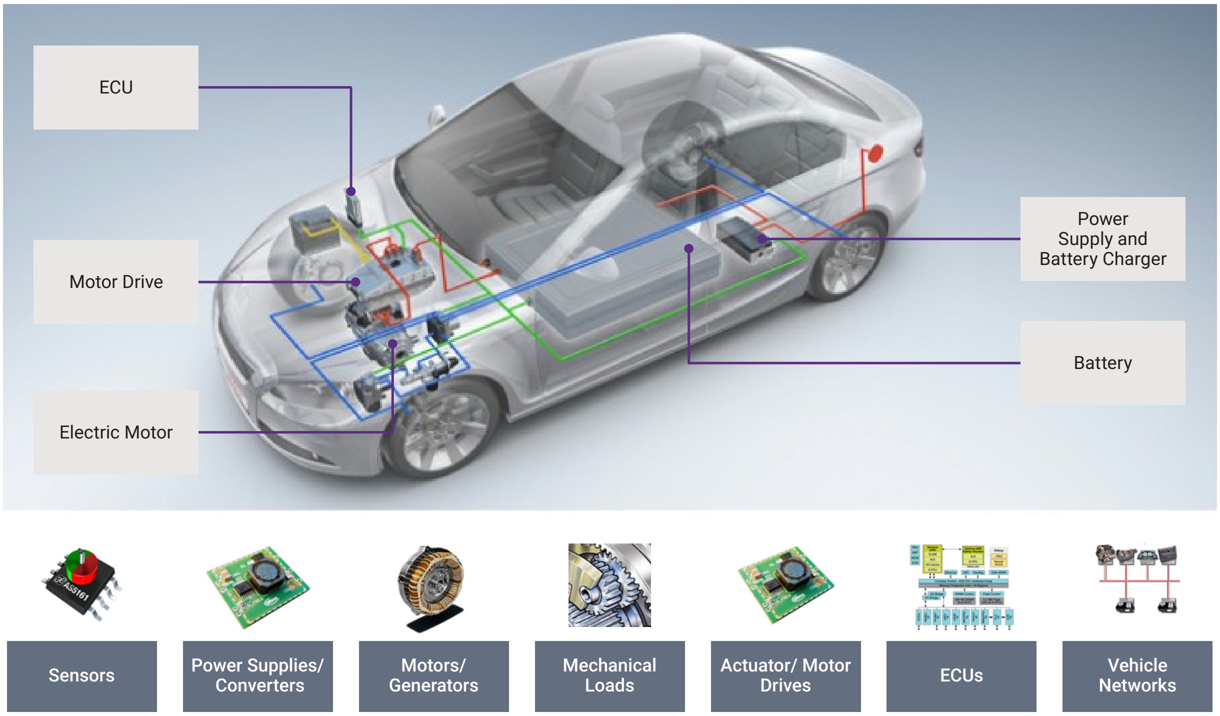

Figure 1: Power electronic system components in an electric vehicle

The market for these systems and the chips that run them is growing. One study from MarketsandMarkets projects a 4.7% compound annual growth rate (CAGR) in the power electronics market over five years, from $35.1B in 2020 to $42.2B in 2025. There are many drivers for this growth. The electrification of transportation is one of the most visible examples. Electric vehicles (EVs) and hybrids have highly sophisticated power electronic systems to manage power for optimal driving range, performance, or some user-selected balance. Relevant vehicle subsystems include the propulsion/powertrain, electronic control units (ECUs), battery charging systems, photovoltaic power conversion, and power factor correction.

Self-driving cars garner most of the headlines, but all types of road and rail vehicles are also increasingly electrified, from trucks and buses to long-haul railroads. Power electronic systems have long been critical components for aerospace applications but will play an even more important role as aircraft systems become more electrified for efficiency and their propulsion systems become electrified as well. Even everyday consumer devices, such as smartphones and tablets, require intelligent power management to preserve battery life while meeting performance and coverage demands. The central chips in such devices may have hundreds of individually controllable power domains so that only the active portions of the electronics are consuming power. Power management in these devices enables them to sense and adapt to changing conditions dynamically.

There are also many industrial applications that require sophisticated power electronic systems. Additionally, "green" legislation and the cost of power mandate that wall-powered equipment must manage power consumption almost as well as devices with batteries. Power electronic systems help to manage the electrical grid, maximizing efficiency while minimizing blackouts and brownouts. For renewable but inconsistent sources such as wind and solar, energy must be converted, controlled, and possibly stored before being fed into the power grid.

Trends in Power Electronic System Development

All the drivers for growth in the power electronics market, especially automotive and aerospace electrification, are having a major effect on the development of power electronic systems. Design complexity is increasing, schedules are compressing, and cost concerns are growing. In many ways, this evolution is paralleling what has been happening over the last few decades in digital electronics. Discrete components were combined into integrated circuits (ICs) and then individual ICs were combined into system-on-chip (SoC) designs.

Power electronic systems contain a mix of digital and analog/mixed-signal (AMS) circuits, but they have followed a similar path. Discrete components were combined into chips, and these are becoming increasingly smart and sophisticated. Power electronic development has advanced to where a system designer can obtain a complete regulator or power converter on a chip. This saves time and design resources, shrinks the physical size of the power electronic system, and often reduces the bill-of-material (BOM) cost for the system.

Both digital and AMS designers once relied primarily on the bring-up lab for verification and validation. The cost of building and maintaining physical prototypes in the lab is significant but minimizing the number of lab set-ups limited the number of engineers who could work during this phase of the project. Digital designers found that the time to find and fix bugs in the lab was unacceptable, and so moved to pre-silicon verification using simulation, backed by static and formal analysis, as their primary method. Although final system validation is still performed in the bring-up lab, design exploration and "what-if" analysis plus many aspects of verification and validation are now performed long before any physical prototypes are built. Further, simulation is often revisited even after production because of its flexibility in helping troubleshoot specific issues found in the field.

AMS designs, including power electronic systems, are more and more following a similar path. Extensive lab testing is being replaced by simulation and virtual prototypes that model the physical design. A comprehensive simulation solution is required for projects of any significant size or complexity. Of course, any simulation is only as accurate as the models used to represent the physical devices. Model availability has become a key factor, sometimes the primary factor, in selecting parts for a power electronic system design and managing the supply chain. Models have overtaken datasheet information as the primary communication mechanism between part supplier and system designer. In fact, the term "model-based design" is sometimes used to describe the flow today.

Requirements for a Solution

An effective verification solution must go well beyond the tedious basic circuit simulations that were once considered adequate. Simulation must now include such advanced capabilities as.

- Design flexibility: multiple abstraction levels, physical domains, and thermal capabilities
- Higher levels of abstraction: faster simulation times with larger designs/systems
- Stability analysis: high-performance AC analysis (linear/periodic)
- Robust design flow: automated analysis for zero-defect/6-sigma design and worst-case conditions
- Functional safety: automated reliability/fault analysis
- Test automation: repeatable tests and flexible scripting

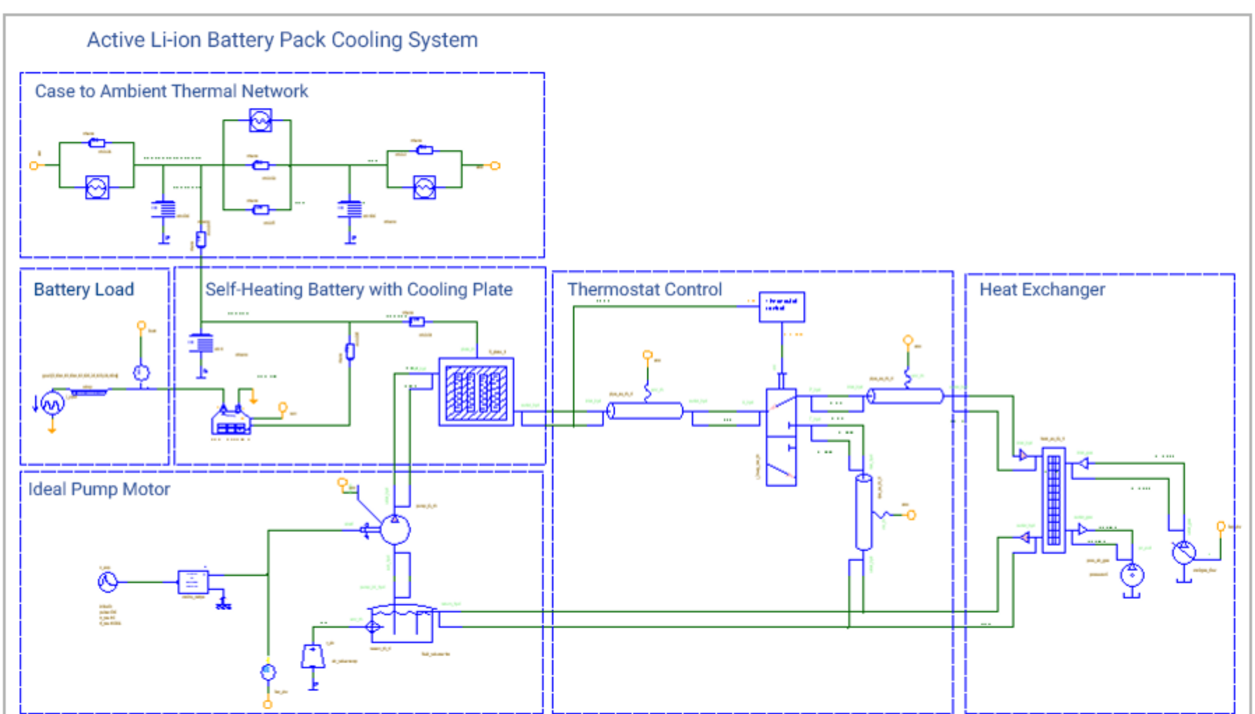

Figure 2: Example of a complex power electronic system

Additionally, the verification solution must be able to support co-simulation using virtual hardware-in-the-loop (VHIL) and virtual processor-in-the-loop (VPIL) environments for hardware and software design and validation. This requirement matches similar trends in the development of digital systems using SoCs with embedded processors. The simulations must be capable of handling the advanced models for emerging aspects of power electronic system design, including the efficient wide-bandgap (WBG) power semiconductor devices used in power converters and motor drives, more efficient battery types and chemistries and their associated management systems, and electromechanical devices and system-level loads modeled using finite element analysis (FEA).

These simulation requirements apply to tools developed by electronic design automation (EDA) providers, but they also place demands on the models provided by the power electronic system suppliers. Often, the best, most accurate models come from the system providers, and these rely on models from the semiconductor suppliers. Moving from hardware prototypes for system and software validation and calibration to virtual prototypes is only possible with highly accurate component models. At the same time, sufficient simulation performance demands behavioral models. Ultimately, an ecosystem for model exchange is necessary to make the modern approach to power electronic system development work.

The Synopsys Simulation Solution

The Saber™ family from Synopsys meets all the requirements for a comprehensive, seamless power electronic system simulation solution. Within the family, two specific products provide two levels of capabilities that cover the complete development process. SaberEXP is a high-speed piecewise-linear (PWL) circuit simulator for power electronic systems. Its integrated simulation environment is tuned for early design exploration and architectural “what-if” analysis. It provides parametric and statistical design capabilities for optimizing and verifying system robustness, analyzing results with a broad suite of measurement and waveform calculation features.

SaberRD is an intuitive, integrated environment for designing and analyzing power electronic systems and multi-domain physical systems. It is ideal for verifying the design implementation, validating circuit parameters, tuning and optimizing the design, and performing reliability analysis. It simulates worst-case conditions and corner cases, while modeling faults and stress effects. It takes advantage of grid and cloud computing resources to run many simulations in parallel. It scales to full system-level integration and verification, handling complex power electronic system designs with no compromises in quality or accuracy.

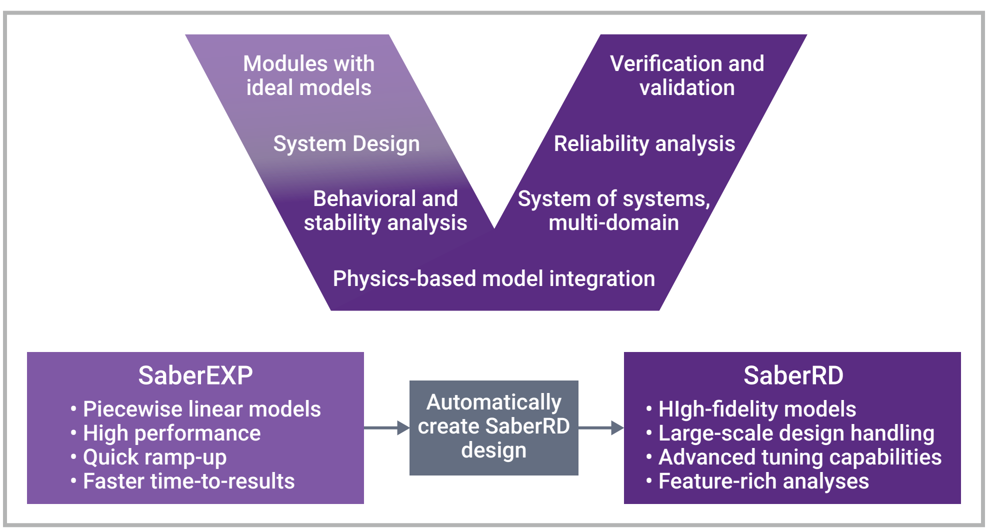

Figure 3: Saber tools in the power electronic system development flow

As shown in Figure 3, SaberEXP and SaberRD fit together in a seamless development environment for power electronic systems. Architects and designers can complete proof of concept and design exploration using abstract models in SaberEXP and then, once parts are chosen and the design is complete, move to detailed simulations with SaberRD. There are variations available in this flow. SaberRD can be run on blocks and subsystems before the complete power electronic system has been integrated. Reciprocally, there are applications late in the development process for which PWL models are sufficient and SaberEXP is a good fit. Both SaberRD and SaberEXP are flexible and powerful enough to satisfy needs at multiple stages of the development process.

As noted previously, fast and accurate part models are essential for simulation using SaberRD. An excellent source of models is the silicon vendors themselves. Synopsys works very closely with suppliers of power electronic systems chips to provide users access to these models with no conversion effort or extra work required. Since many semiconductor vendors have their own in-house circuit simulation tools, this process may involve certifying that the results from SaberRD match those from the vendor's internal simulator. This also frees users from having to correlate or validate the simulation runs performed by SaberRD.

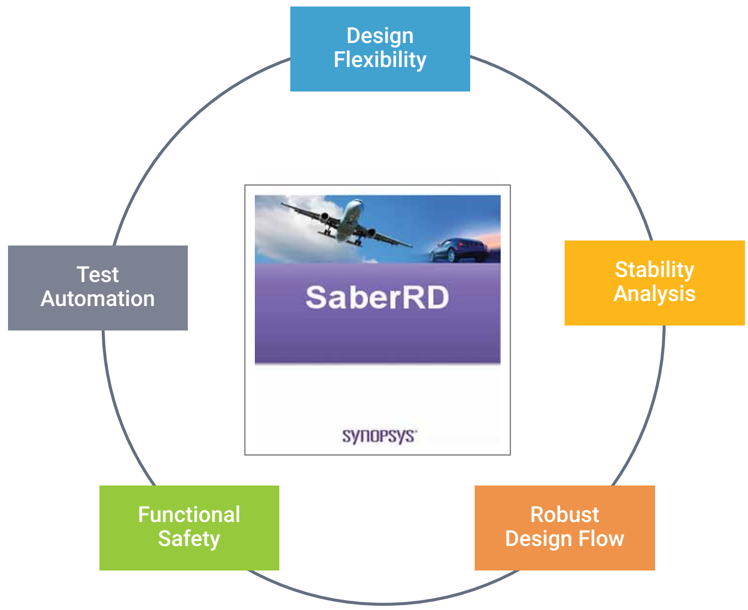

Figure 4: Benefits of SaberRD

Analog Devices µModule Example

Among the many chip options available to designers of power electronic systems, the µModule® (micromodule) power products from Analog Devices (ADI) are some of the most advanced and sophisticated. These are system-in-package solutions that integrate high-performance analog ICs, power switches, and passive components. Functions available include DC-to-DC converters, battery chargers, and a wide range of regulators. Synopsys has worked side-by-side with Analog Devices to provide models of µModule products that are fully qualified by ADI for simulation with SaberRD.

As shown in Figure 5, the process of validating the µModule models for SaberRD is exacting to ensure the highest possible accuracy. Analog Devices' internal LTspice simulator is ADI's gold standard for modeling. The models used in LTspice are converted to Saber models automatically via a translator. The schematic for the part in the simulator testbench is replicated in SaberRD and each simulation is run using the industry-proven SaberRD engine. The results from LTspice and SaberRD simulations are compared, and the model is considered validated only when all simulation results match. Qualification engineers have the ability to zoom in on very fine details of the waveforms to ascertain that any tiny variations are within acceptable limits.

Once the model is fully validated, it is encrypted and made available in the SaberRD library. Users can select any available ADI part/component from an intuitive pulldown menu. In addition to running SPICE-level simulations, users can take advantage of the unique capabilities of SaberRD by running system-level use cases, including multi-domain/thermal, high-performance AC analysis, functional safety, and test automation.

An example of the benefits of having the models in SaberRD is doing stability analysis. It is critical to determine the stability of control systems, and stability analysis requires frequency domain or AC analysis to produce Bode plots. Traditionally, circuit simulators do fine with AC analysis on analog circuits since it is possible to find the bias point needed for frequency domain analysis. However, modern power electronics all involve switching, so traditional AC analysis breaks down. This left many engineers having to go to the lab and build expensive prototypes to perform stability analysis. SaberRD solves this problem with Periodic AC Analysis. This powerful capability allows engineers to produce Bode plots and examine stability even on switching circuits. This saves resources and ensures stability much earlier in the design cycle, where it is more efficient and cost effective to make design changes.

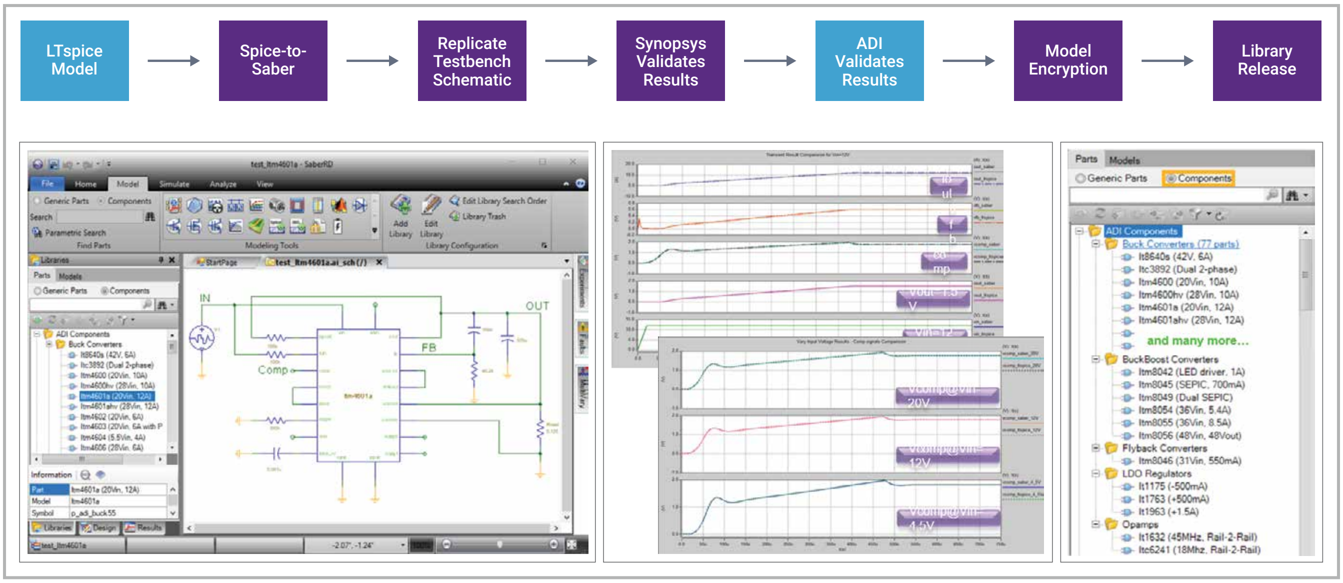

Figure 5: Validation of a SaberRD μModule model

Summary

Power electronic systems are growing in size and complexity, driven by a wide range of applications from small consumer devices to huge industrial plants. Finding issues in lab prototypes is costly and delays project schedules, so simulation is required. The Synopsys Saber family provides a complete end-to-end solution, with SPICE-level accuracy available in SaberRD's component model libraries. Synopsys works closely with semiconductor suppliers to ensure the accuracy of the models, including the popular and powerful μModule power products from Analog Devices. SaberRD is the first system simulation tool to feature ADI component models. This partnership accelerates time to market, reduces development costs, and increases product robustness while enabling power electronic system success by mutual customers.

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