

AUTOMOTIVE Design Line

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Simulation-based design integration improves hybrid vehicle reliability

Because of integration requirements, hybrid vehicles are among the most complex systems to design, manufacture, and maintain. Robust Design methodology provides the framework to design reliable hybrid vehicle systems.

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Hybrid cars have become increasingly popular options for commercial and personal transportation in order to save energy (and cost) and cut emissions.

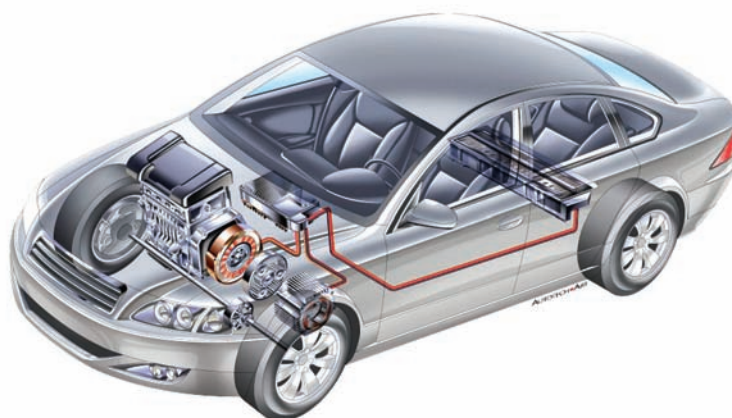
Electric vehicles were previously developed to attack the problems of higher fuel costs and increased tailpipe emissions. They suffered, however, from limited driving range and lack of support infrastructure (i.e. charging stations). The hybrid vehicle was advanced as the bridge between the internal combustion engine and electric vehicles. Hybrid vehicles offer the increased fuel efficiency and reduced emissions of the electric vehicle, and the long-distance range and readily available support infrastructure of an internal combustion engine vehicle.

In a hybrid vehicle, the drive train contains components from both the internal combustion engine and electric vehicles. The list of system components includes a battery pack, an electric motor/generator, and an internal combustion engine. The internal combustion engine provides electric and mechanical power to the system. The electric motor/generator and battery pack provide an electric drive for the system and a way to store electrical energy. Drive trains for hybrid vehicles come in three configurations: series, parallel, and combined series-parallel. Regardless of the configuration, reliable vehicle operation depends on the successful integration of the drive train components.

Mechatronic systems

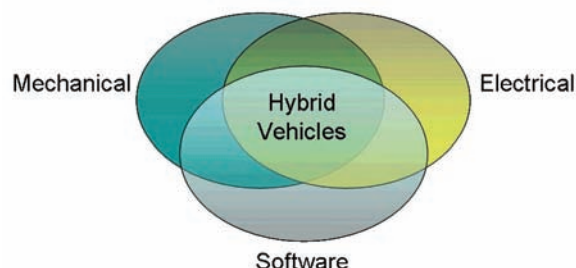
Both standard and hybrid vehicles depend on the integration of electrical, mechanical, and software technologies, where automotive electronics and software are used increasingly to control or replace mechanical operations. The intersection of these three design disciplines is called mechatronics. Hybrid vehicles are the locus of a mechatronics design.

Combining these technologies in a standard vehicle, where electronic and software control is used in non-drive source applications, is a complicated design challenge. A hybrid vehicle has this same

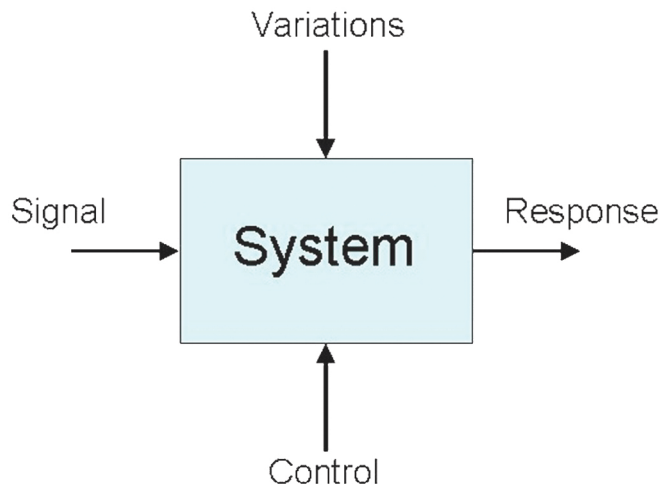


Key hybrid passenger car power train systems include the motor/generator (front), controller (center), and battery pack (rear).

design challenge of integrating non-drive automotive electronics source systems, with the added complexity of electronic and software control of the vehicle drive. Because of this integration requirement, hybrid vehicles are among the most complex systems to design, manufacture, and maintain.



Hybrid vehicles depend on the efficient integration of mechanical, electrical, and software technologies.



The general Robust Design system diagram is based on Taguchi methods.

As vehicle complexity increases, so do concerns about reliability. Designing hybrid vehicle systems, therefore, requires a systematic, organized approach to development. To ensure system reliability, this organized approach requires that reliability issues be an integral part of the design process from the very beginning. A Robust Design methodology provides the organized framework needed to design reliable hybrid vehicle systems.

A Robust Design methodology is an organized and proven development philosophy designed to improve system reliability. The principles of Robust Design allow design teams to handle complex system integration issues with repeatable processes. As shown below, a Robust Design-based system accepts input signals and produces an appropriate response. In a typical environment, however, variations in the design can influence the performance of the system. Design teams must implement control techniques to compensate for the design variations.

A Robust Design flow is focused on reducing the effect of variations on system performance and reliability. These variations can come from sources internal or external to the design and include changes in component tolerances, manufacturing processes, use patterns, the environment, and those due to system aging. While these are broad categories, each factor can have a major effect on the reliability of a system. The key objective of a Robust Design process is to optimize the system design for performance, reliability, and cost while accounting for these variations.

In a typical design flow, accounting for multiple variations requires extensive testing. This means that once a system has been designed, it must be prototyped and tested. A Robust Design process requires that multiple variations be tested, which means a new prototype has to be built and tested for each variation. It is obvious that implementing Robust Design methodologies using this design-prototype-test flow would soon become too time consuming and expensive to be practical.

The solution is to move the design-prototype-test operations into the virtual world of simulation and analysis. This is often referred to as virtual prototyping. With modern design tools like the Saber simulator, design teams can design and build virtual prototypes of their

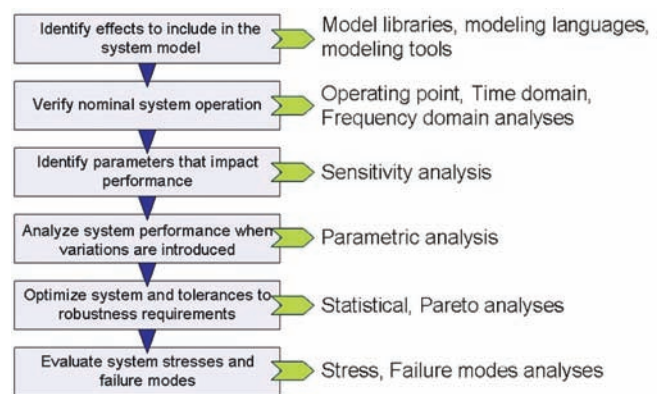
systems and run many tests within the time and budget allotted for the traditional design-prototype-test flow. Simulation and modeling, therefore, are critical requirements to implementing a Robust Design flow.

Design flow

A Robust Design flow based on modeling and simulation must follow a systematic process. The key to this process is determining:

- The critical performance metrics of the system
- Modeling the system in a way that highlights these metrics
- Then verifying the metrics at each stage of the system development process

A Robust Design flow has the fundamental development stages and requires the simulation capabilities shown here.



An effective Robust Design process depends on a systematic development flow and requires advanced simulation capabilities.

This Robust Design flow can be easily illustrated using the development process of a hybrid vehicle system.

Performance metrics are derived from the design specification. A typical hybrid vehicle design specification will contain several performance requirements. As an example, the vehicle will often be required to meet emission, performance, and fuel economy requirements. Each of these requirements becomes a performance metric that must be analyzed during the design process. For the current discussion, fuel economy will be used as the critical performance metric.

With the fuel economy metric selected, the design team must choose or develop simulation models that highlight the design variations that affect the metric. Because the Robust Design process can be simulation intensive, models should be chosen that optimize both simulation accuracy and simulation performance.

When developing models for use in a Robust Design flow, design teams should use a hardware description language (HDL) to create the models. Using an HDL gives the team better control over model accuracy and performance, including the ability to create models at different levels of design abstraction. The MAST language from Synopsys is the de-facto standard in the automotive industry for modeling vehicle systems. Another option is the VHDL-AMS language, recently standardized by the IEEE. Both languages are supported by the Saber simulator.

Verify nominal system operation

Once the system is modeled to focus on analyzing the fuel economy, the next step is to verify the nominal fuel economy performance of the hybrid vehicle. The nominal analysis shows the design's best case fuel economy under ideal conditions. The design is analyzed using standard operating point, time domain, and frequency domain analyses. The fuel economy results from the nominal analysis become the performance benchmark for the remaining steps in the Robust Design flow.

Identify parameters that impact performance

The hybrid vehicle model should contain parameters for the critical variations that affect the fuel economy. These variations are selected by the design team based on their knowledge of the vehicle system. Once the variations are chosen, the team needs to identify those that most affect the vehicle's fuel economy.

A sensitivity analysis is the most effective way of analyzing the parameters that most affect a system. Using a sensitivity analysis, the fuel economy of the vehicle can be analyzed with respect to changes in individual system parameters. These parameters, and the affect they have on the hybrid vehicle's performance, become the focus of the rest of the design process.

Variations analyze system performance

With the critical parameters identified, the next step is to investigate how changes in these parameters affect the hybrid vehicle's fuel economy. Based on their knowledge of the system, design teams establish value ranges for the critical parameters, and set up simulation commands for sweeping the values through their ranges.

Being able to sweep the parameters is an important capability. Design teams must set up the simulation to sweep the design parameters in a series of loops that the simulator can automatically execute. This allows the simulator to cover every possible combination of the parameters, giving the design team a complete picture of how the fuel economy is impacted. The objective of a parametric analysis is to establish a range of values for each critical system parameter. This range of values is then translated into a nominal value plus a tolerance for use in a statistical analysis.

Optimize system performance

At this point, the design team should have a good understanding of how system variations affect fuel economy, how compensation techniques should be implemented, and which components should be selected to give the best system performance. The next step is to verify the vehicle's fuel economy over all possible combinations of design parameter values.

This is accomplished using a statistical analysis. Based on the results of the parametric analysis, design teams assign tolerances and distributions to identified key parameters in the system. The list of key parameters should include those found during the sensitivity

analysis. The objective is to verify the vehicle's fuel economy as design parameters are randomly varied within their tolerance ranges and combined with other parameters in the design. The end result should be a hybrid vehicle whose fuel economy is optimized over a broad range of system variations.

Evaluate system stresses and failure modes

The final step to ensure system reliability is to analyze the stresses placed on system components, and then investigate what happens when key components in the system fail.

A stress analysis is used to analyze the impact stresses place on the hybrid vehicle components. Design teams place maximum stress ratings on these components, and apply de-ratings where needed. The simulator uses this information to determine how near "maximum" or "de-rated" ratings the component is being operated. The design teams can then take corrective action where needed.

A failure modes analysis verifies system performance as key components are initiated into failure modes. Design teams must first choose an acceptable range for the fuel economy measurement. Key components are then selected to fail during the analysis, and the failure mechanisms for the components are defined.

The failure modes analysis then runs a series of analyses causing the selected components to fail. The fuel economy is monitored during the analysis to see if the system, even after failures occur, continues to perform within specification. The end result is a report giving details of the component failures and the pass/fail state of the fuel economy metric.

Conclusion

Hybrid vehicles are new and evolving complex transportation systems. Their integral use of mechanical, electrical, and software technologies makes system integration more challenging and the design process significantly more complex than for conventional vehicles. The hybrid system's high complexity can result in increased reliability issues. Design teams need an organized design approach to address these system complexities and ensure that reliability objectives are met.

Robust Design methodologies provide a systematic design approach for complex systems. And incorporating Robust Design principles with virtual prototyping practices, including modeling and simulation, gives design teams powerful tools for optimizing the performance, reliability, and cost of hybrid vehicles. To make a Robust Design flow work for a hybrid vehicle development program, design teams need access to advanced simulation tools like the Saber simulator from Synopsys. Using these tools, design teams have the ability to analyze and verify the performance of complex hybrid vehicle systems.

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