Feature Article

Solutions for Testing Hybrid Powertrains

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The rapid increase in development activities on hybrid powertrains is creating unique challenges for the management of powertrain development facilities and the test equipment suppliers to these facilities. In this article, the integration of the powertrain engineering design phase, the control and electric power management activities and the test facility, and vehicle based powertrain development phases including the use of hardware-in-the-loop (HIL) is reviewed. The specific powertrain features of both current and future hybrid powertrains are reviewed and the subsequent test equipment and test process requirements are translated down to specific equipment and operational solutions.

Introduction

The significant increase in the number of hybrid electric vehicles (HEV), both already in production and under development, has created an urgent need within OEM's and Tier 1 powertrain suppliers to have the appropriate test facilities, tools and development methodologies for HEV powertrain systems. While many of the features and characteristics of HEV powertrains are similar to conventional gasoline and diesel powertrains, there are key technology and performance differences that place new requirements on the development process.

A HEV contains an optimised mix of various powertrain components depending on the hybrid variant. There are commonly three different types of hybrid powertrain, Micro, Mild and Full; these are described later. As shown below by the US Department of Transportation, a HEV powertrain, depending on the version, will contain many components and systems not normally seen in a conventional automotive powertrain. As shown in Figure 1, the main systems within a hybrid powertrain may include:

- Traditional power units such as gasoline and diesel engines
- Electric motors and controllers
- Electrical energy storage systems such as batteries and ultracapacitors*1
- Plug-in charging for mains recharging of batteries
- Fuel systems for the hybrid power units
- Integrated transmissions and controllers

*1 : Ultracapacitor: capacitor with high energy density and low impedance.

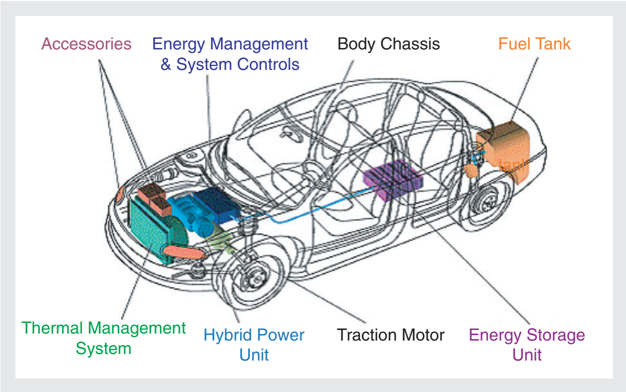

Figure 1 HEV Powertrain Components

Adding a further complication to the development process for a hybrid powertrain is the overall energy management within the powertrain that is designed to work as an integrated whole. Sophisticated power management within the integrated driveline is essential to achieve the vehicle performance goals including fuel economy, exhaust emissions and driveability. Within a HEV this may also include the braking system. In conventional vehicles, the energy from deceleration is wasted. In some hybrid vehicles, regenerative braking systems capture that energy, store it, and convert it to electricity to help propel the vehicle, ultimately increasing overall efficiency. Some hybrids also use ultracapacitors to extend the life of a hybrid vehicle's on-board battery system because they are better suited to capturing high power from regenerative braking and releasing it for initial acceleration.

Finally, within the compressed and concurrent development processes of typical powertrain and vehicle development projects, frequently there is a need to accurately simulate elements of the final powertrain and vehicle that are not available during the development process.

Hybrid Powertrain Technologies

Hybrid systems can offer improved fuel economy in congested driving conditions. Stop/ start and low speed urban driving suits hybrids. Diesel powertrains are more efficient in higher speed, less congested traffic conditions, where higher speed operation requires high efficiency combustion and power transmission systems. However, despite the significant commitment to diesel systems, European manufacturers are developing hybrid technologies. There are growing environmental pressures, customer demand is increasing, the cost and complexity of diesel aftertreatment is rising, and there is the need to source global product line ups.

Micro hybrid technology is currently in development and production with several European manufacturers and suppliers. The technology is modular and can be added straightforwardly to existing powertrain systems using an uprated starter alternator, with relatively conventional electrical and battery systems. The technology supports engine stop / start operation.

Mild hybrid technology is also in development and production, in Japan and Europe. The technology is typically less than 30 kW, and is mechanically integrated with the powertrain. Significantly higher voltage electrical systems are used, greater than 100 V, with improved battery technology, for example nickel-metal hydride (NiMH) and lithium ion (Li-Ion) batteries. The technology supports engine stop / start operation and regenerative braking. The higher power level provides a potential for increased performance and some engine downsizing.

Full hybrid systems are in development and production in the US and Japan, with Europe following. Hybrid power levels are up to about 80 kW and voltages can exceed 300 V. As well as NiMH and Li-Ion batteries, energy storage with supercapacitors is under consideration. Unlike Micro and Mild hybrid systems, Full hybrid systems have an electric only mode of operation, where propulsion is achieved with the engine stopped. This is typically used in urban driving at low speeds. The higher power levels of the Full hybrid enable increased fuel economy and vehicle performance benefits.

Micro and Mild hybrid mechanical integration takes place with the engine; Micro hybrids involving the engine accessory drive and Mild hybrids the engine output and flywheel. The Full hybrid requires significant integration with the transmission or driveline, and involves a more complex package and increase in weight.

Development Requirements

Each type of hybrid system has specific development requirements, but in general the demands on the development process are cumulative as the technology progresses from Micro to Mild through to Full hybrid technology.

Micro Hybrid Powertrain Systems

Engine Mechanical Systems

Figure 2 shows a Micro hybrid schematic. Given the relatively minor hardware changes associated with Micro hybrids, the incremental requirement this places on the test facilities is small. The engine in many cases is still developed as a separate package from the transmission and driveline allowing conventional engine development testbeds to be used. However the increased transient loading on the front end starter/alternator does require additional front end alternator drive (FEAD) testing, ideally including rig testing with engine torque simulation.

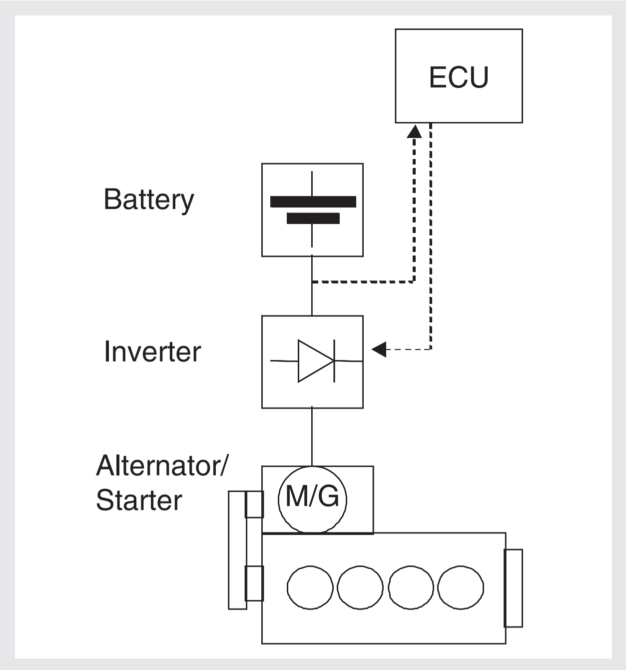

Figure 2 Micro Hybrid Schematic
ECU: Engine Control Unit

Engine Electrical Systems

The 12V to 42V electrical systems typically used are relatively conventional although it is likely that overall power levels will increase. Energy management control is generally minor and included within the conventional engine management system but will require the ability to provide battery simulation within the engine testbed.

Hybrid Drive Systems

As the hybrid drive system is limited to a FEAD and stop / start driving characteristics, there are no additional development requirements in this area.

Transmission

There are no additional development requirements for the transmission.

Powertrain Operational Modes

The dominant operational mode is stop/start. Simulation of this on a testbed requires the ability to disconnect or declutch the engine from the test driveline. The simulation of low level regenerative braking dictates motoring capability but this is commonly managed with current generation motoring engine dynamometers.

Mild Hybrid Powertrain System

Figure 3 shows a Mild hybrid schematic. Mild hybrids present a much greater challenge to the development process and facilities given the integrated nature of the combustion and electrical power units. Building on the comments on micro hybrids, two fundamental approaches to the powertrain development are necessary:

- Component/module development with extensive simulation of the rest of the powertrain
- Full powertrain integration and calibration

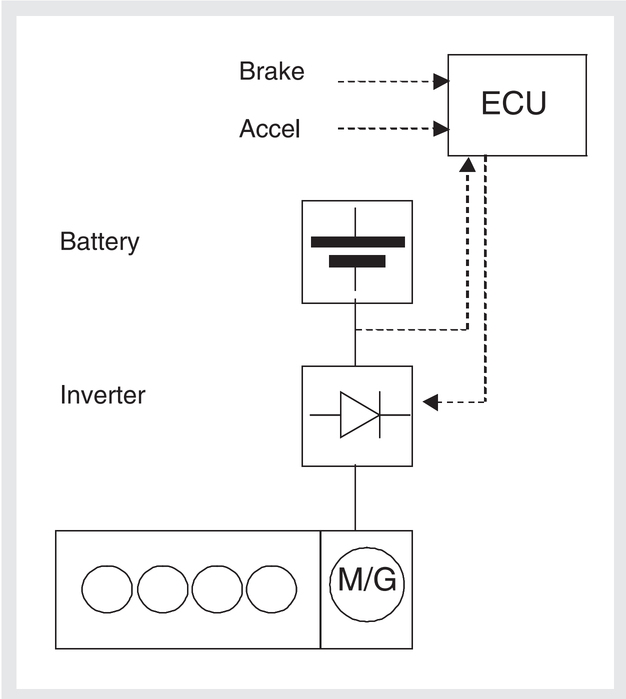

Figure 3 Mild Hybrid Schematic
ECU: Engine Control Unit

Mechanical, Electrical and Hybrid Systems Development

There are several relatively easy ways to divide up a Mild hybrid powertrain into manageable sections and take a modular approach to the overall system development. It is reasonable in early stage development to focus on individual components or modules while simulating the remaining portions of the driveline. The keys to success in this modular approach are:

- Consistency of the simulation models from control system development to all component testing applications
- Consistency of test procedures using load profiles based on real world data rather than fixed load profiles
- Flexible HIL*2 systems that can be integrated into various testing applications
- Availability of appropriate loading devices including:
  - battery electrical testing via flexible power sources up to 144 V
  - inverter electrical testing via flexible power sources up to 144 V
  - engine and generator mechanical testing with conventional dynamometers
  - engine only mechanical testing via ultra-low inertia dynamometers
  - climatic and vibration simulation for inverter and battery components
  - environmental simulation for component testing through to full powertrain and vehicle testing

Given the higher overall torque available from a hybrid powertrain at lower engine speeds, many engine testbeds will require resizing to a high torque capacity dynamometer if combined engine and electrical motor testing is required.

*2 : HIL: Simulation system to test vehicle components under the equivalent condition to complete vehicle.

Transmission

With the addition of regenerative braking and energy recover systems, final powertrain calibration requires full powertrain testing including individual wheel dynamometers capable of simulating on road regeneration situations up to 30 kW.

Powertrain Operational Modes

The main operational modes utilised by Mild hybrids are stop /start (as with Micro hybrids), regenerative braking, integrated torque management for launch assist, overtaking and braking manoeuvres. All of these are covered by the various changes noted above.

Full Hybrid Powertrain System

Figure 4 shows a Full hybrid schematic. The Full hybrid adds to the development challenges of the Mild hybrid. The main incremental challenges with Full hybrid powertrains are:

- The addition of a power split transmission (potentially continuous variable transmission (CVT))
- Significantly higher voltage and power electrical generation and motoring
- Further advanced energy management systems

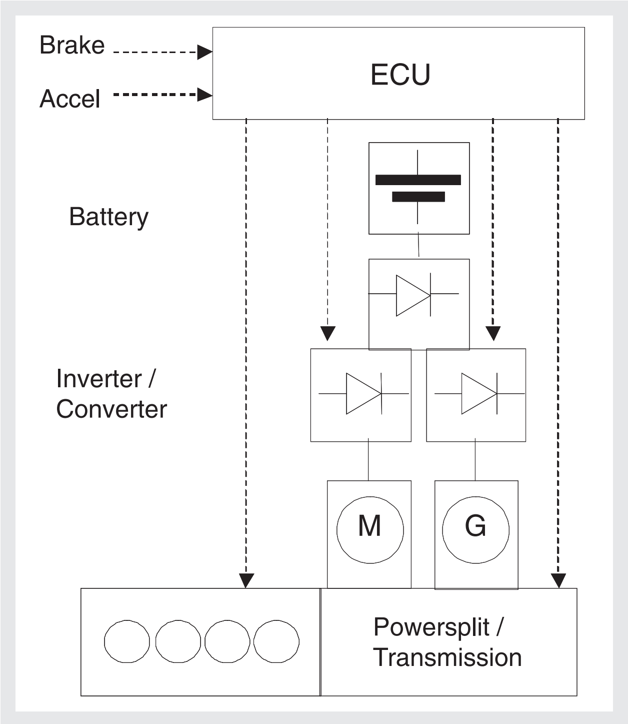

Figure 4 Full Hybrid Schematic
ECU: Engine Control Unit

Mechanical, Electrical and Hybrid Systems Development

As discussed with the Mild hybrids, individual components or modules in the driveline will be developed in isolation using simulation for the missing elements of the driveline. However with the high power electric motor (e-motor) the rigs will require high speed high torque capabilities and the overall performance of the electrical power systems under extreme climatic conditions will need to be evaluated. The power voltage required can be of the order of 500 V with the systems electrics at 300 V.

The hybrid control systems and energy management are highly complex on a Full hybrid and the ability to include HIL as discussed with Mild hybrids is essential. It is estimated that the calibration effort for a Full hybrid is a minimum of 4 times that required for a conventional engine only powertrain.

Transmission

The power split device will be considered within the transmission development and can only be effectively developed and calibrated on a full powertrain rig with individual wheel absorption and regeneration capabilities. If necessary the engine can be simulated by an ultra-low inertia motoring input motor capable of simulating the cyclic torque fluctuations of the combustion engine. Again as with the electrical systems, the performance of the power split device under extreme climatic conditions must be evaluated. This is best simulated on a powertrain rig with full temperature and humidity capability.

Powertrain Operational Modes

In addition to stop / start operation and regenerative braking systems, the Full hybrid uniquely has an electric only mode. The integration and operation of this with other operating modes of engine and transmission also requires evaluation on a powertrain rig. Given the low speed high torque characteristics of the e-motor, this will place new demands on the torque envelope required from the powertrain dynamometers.

HEV Exhaust Emissions Measurement

The necessary constant volume sampling (CVS) systems and test procedures have already been developed and established for low emissions powertrains including the use of multiple venturi flow measurement capable of switching during phase changes in the drive cycle. The required low concentration analyzers optimised for reading of dilute bag samples are also already available. Alternative technologies such as Bag Mini-Diluter systems and direct exhaust gas flow measurement have been developed to meet the super ultra low emission vehicle (SULEV) requirements in US and these are inherently suitable for the low overall emissions expected from hybrid systems. However the stop/start operational modes used by all hybrid versions do require the emission measuring systems be modified so that there is no suction on the vehicle exhaust when the engine is stopped.

Conclusion

The growth in HEVs is bringing rapid and unique challenges into the powertrain development area. Driven by the need to develop vehicles with improved fuel economy, reduced exhaust emissions and acceptable driving performance, the automotive industry has clearly decided that hybrid powertrains can meet these market needs, at least in the North American and Japanese markets initially. A range of technologies, ranging from Micro hybrids, through Mild hybrids to Full hybrids are now in production with many more systems under rapid development.

The implications of these hybrid powertrains on development facilities and methodologies varies significantly depending on the technology employed. Micro hybrids impose very little additional challenge while Mild and Full hybrids bring significantly new challenges. However it is also clear that the calibration of complex hybrid powertrains, with sophisticated energy management within the powertrain, can only really be done effectively on full engine driven powertrain rigs with individual wheelhub absorption and control capabilities. Adding environmental simulation capability in terms of temperature, humidity and occasionally pressure has the added benefit of providing repeatable extreme test conditions without depending on extensive travel to climatic test sites.

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