SHC PROJECT SUMMARY REPORT

Overall Monitoring and Diagnosis of Hybrid Vehicles in Realistic Scenarios

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Summary

Hybrid vehicles provide a new level of complexity compared to traditional vehicle design when it comes to control, diagnosis and system safety. The reason is that there are more components, both physical and software, that interact in non-trivial ways, which as a further complication also depend on driver behaviour and traffic situation. Because of this reality there is a need for tools that integrate these complex aspects and make analysis, design and simulation possible. The purpose of this project is to investigate how these components interact with diagnosis system on vehicle level. This means that the emphasis in the project is diagnosis of several components in the powertrain using one diagnosis system. The systems are also to be evaluated in realistic scenarios, since otherwise there is a risk that the developed methods do not take the full benefit of the interplay vehicle/driver/mission/control/diagnosis. One example of interplay is that different control structures can either hide or attenuate a fault, and by that making it more or less difficult to diagnose that fault.

A simulation platform is designed in the project and several diagnosis systems are designed and evaluated in this environment. The vehicle considered is a long haulage parallel hybrid truck. It is found that the interaction between the operating points of the components in the powertrain significantly affects the diagnostic performance, and thereby it is advantageous to consider the diagnostic aspects when designing the overall energy management of the vehicle. Further, a new low complexity model of the electric machine is developed that better describe the power losses of the machine compared to a standard model. The benefit of this modelling improvement on the fault diagnostics is shown in a case study. Two more generic diagnostic methods are also developed that improve the diagnostic performance, and the feasibility of these methods are illustrated by the HEV application.

The project was lead by a reference group represented by Scania and Volvo AB, and initially also BAE systems. The project started in January 2008 and finished December 2012 (dissertation defended April 2014) with an annual budget of 900 kSEK.

Background

A diagnosis system monitors a physical system or component to determine whether there is a fault or not in the system. A first step is to discover that a fault has occurred, but it is also desirable to pinpoint what part of the system that is faulty. Monitoring of the components in a vehicle powertrain is important for several reasons, for example to fulfil legislation requirements, safety demands, maximize vehicle up-time, and efficient repairs. When a vehicle is hybridized, which in this project is achieved by the internal combustion engine propels the vehicle in combination with an electric machine, the complexity increases leading to high demands on the diagnosis system monitoring the vehicle. It is common that there is one diagnosis system monitoring each component in the powertrain, but here benefits by designing one diagnosis system monitoring several components in the vehicle are studied. In hybridized vehicles there is a freedom in how to use the electric machine and the combustion engine to propel the vehicle. Therefore it is important to study how the design of the overall energy management strategy affects the possibility to fault monitor the vehicle.

In the project consistency based diagnosis is used, meaning that a mathematical model of the vehicle is compared by sensor signals to determine whether the vehicle is faulty or not. By using diagnostic methods it is also possible to, at least to some extent, pinpoint what component that is broken and in what way.

General project description

There are three types of objectives and goals in the project. One type is to provide a prototype tool that demonstrates integration of vehicle, driver, mission, overall control (energy management), and diagnosis, with emphasis on the diagnosis. Another type of goal relates to the fact that new research is needed for monitoring and diagnosis in this context. Once again it deserves to be mentioned that different drivers, or driver models, and different driving missions will excite different behaviours influencing the diagnosis capability. To validate the results realistic scenarios needs to be used, and this is done in the project by using recorded data from a truck driving on the highway between Linköping and Jönköping in the evaluation process.

Achieved results

One outcome of the project is simulation platform including a powertrain model of a parallel hybrid vehicle parameterized as a heavy duty truck as well as several diagnosis systems. A main contribution in the platform is a new low complexity model of the electric machine. It is shown that this new model describes the power losses better than a standard model when evaluated on measurement data, and that this modelling improvement results in a better signal separation between the fault free case and when there is a fault in the system. Thereby it is easier to design an accurate diagnosis system based on the new model.

Several diagnosis systems have been designed and implemented in the simulation environment. Simulations show that there for example is a connection between how the powertrain components are operating and the diagnostic performance, and that this connection is of greater relevance when few sensors are available.

The basis in the designed diagnosis systems is to construct so called residual generators, that investigate whether the truck model is consistent with the measurements. It is possible to construct thousands of residual generators based on a model of a complex physical system. The sensitivity to faults is different in these, and therefore a systematic method that investigates the properties of all residual generator candidates based on a system model has been developed. In a diagnosis system the residual signals are post processed in and methods for this has also been developed. Further, a method has been proposed that combines an accurate model for the fault free case with another model of the same system describing how the faults affect the monitored system. This results in that it is possible to find a fault and at the same time pinpoint what part of the monitored system that is faulty without extensive modelling. The proposed methods are generic, but to demonstrate feasibility of these methods simulation studies using the truck model have been carried out, and it is shown that the designed methods significantly increase the diagnostic performance.

Contribution to hybrid vehicle technology

The contributions are twofold. The first contribution is the diagnostic aspects including the study of the interaction between the energy management and the diagnostic performance, but also an automatic algorithm to help the designer of the diagnosis system to find residual generators that perform well. When designing a diagnosis system of a hybrid vehicle this kind of tool is of importance since the diagnostic systems are to be developed from scratch, which commonly is not the case for a conventional vehicle since these diagnosis systems has evolved over decades.

The second area of contribution is the developed simulation model of the parallel hybrid truck. Especially the new low complexity model of the electric machine that shows a good description of the power losses of the machine when evaluated to measurements. Accurate models are valuable not only in the design of diagnosis systems, but also in the pre-development phase of new powertrains

Uniqueness and news value

As far we are aware of there is no work is previously done on vehicle level diagnosis of hybrid vehicles. Further, the value of using systematic methods in the design process of a diagnosis system is demonstrated and exemplified on the hybrid vehicle application. A diagnostic scheme combining a map based model with fault models to achieve good diagnostic performance without extensive modelling or measurements of the fault cases is presented.

Timing and finance

The project started January 2008 and lasted till December 2012. The licentiate thesis was defended in May 2011 and the dissertation in April 2014.

The total project budget is SEK 4.5 million, all funded by SHC.

Executors and collaboration

The project was a PhD project, and all work was done by the PhD student with regular supervision. The project was lead by a reference group with representatives from Scania and Volvo AB, and initially also BAE systems.

Papers and publications

Doctoral thesis

- Model Based Vehicle Level Diagnosis for Hybrid Electric Vehicles, Christofer Sundström (2014), PhD thesis, No. 1589, Linköping University.

Licentiate thesis

- Vehicle Level Diagnosis for Hybrid Powertrains, Christofer Sundström (2011), Lic thesis, Linköping University. LiU-TEK-LIC-2011:27, Thesis No. 1488.

Journal papers

- Selecting and Utilizing Sequential Residual Generators in FDI Applied to Hybrid Vehicles, Christofer Sundström, Erik Frisk, and Lars Nielsen (2014), In: IEEE Transactions on Systems, Man, and Cybernetics: Systems, 44(2):172-185.
- Robust Driving Pattern Detection and Identification With a Wheel Loader Application, Tomas Nilsson, Peter Nyberg, Christofer Sundström, Erik Frisk, Mattias Krysander (2014), In: International Journal of Vehicle Systems Modelling and Testing, 9(1):56-76.
- A New Electric Machine Model and its Relevance for Vehicle Level Diagnosis, Christofer Sundström, Erik Frisk, and Lars Nielsen, Submitted to International Journal of Modelling, Identification and Control.
- Diagnostic Method Combining Map and Fault Models Applied on a Hybrid Electric Vehicle, Christofer Sundström, Erik Frisk, Lars Nielsen, Submitted to IEEE Control Systems Technology.

Conference papers:

- Fault Monitoring of the Electric Machine in a Hybrid Vehicle, Christofer Sundström, Erik Frisk, and Lars Nielsen, (2013), In: 7th IFAC Symposium on Advances in Automotive Control, Tokyo, Japan.
- Fuel Efficient Speed Profiles for Finite Time Gear Shift with Multi-Phase Optimization, Xavier

Llamas, Lars Eriksson, and Christofer Sundström (2013), In 54^{th} conference on Simulation and Modeling, Bergen, Norway.

- Residual Generator Selection for Fault Diagnosis of Hybrid Vehicle Powertrains, Christofer Sundström, Erik Frisk, and Lars Nielsen (2011), In: IFAC World Congress. Milano, Italy.
- Adaptive Control of a Hybrid Powertrain with Map-based ECMS, Martin Sivertsson, Christofer Sundström, and Lars Eriksson (2011), In: IFAC World Congress. Milano, Italy.
- Overall Monitoring and Diagnosis for Hybrid Vehicle Powertrains, Christofer Sundström, Erik Frisk, and Lars Nielsen (2010), In: 6th IFAC Symposium on Advances in Automotive Control. Munich, Germany.
- Sequential residual generator selection for fault detection, Daniel Eriksson and Christofer Sundström, accepted for publication in 13^{th} European Control Conference, Strasbourg, France.

Supervised Master thesis

- Electric Motors for Vehicle Propulsion. Martin Larsson, 2014.
- Optimal Speed Profiles for Passenger Cars with Gear Shifting. Xavier Llamas Comellas, 2012.
- A Control System for Battery Charging in Buses. Therese Kjelldal, 2011.
- Starter Motor Protection. Daniel Gerhardsson, 2010.
- Optimization of Fuel Consumption in a Hybrid Powertrain. Martin Sivertsson, 2010.
- Estimation of distance to empty for heavy vehicles. Nils Eriksson, 2010.
- Development and Analysis of Synchronization Process Control Algorithms in a Dual Clutch Transmission. Andreas Gustavsson, 2009.
- Fuel Level Estimation for Heavy Vehicles Using a Kalman Filter. Peter Wallebäck, 2008.