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Model-based development of fuel cell systems for heavy duty trucks

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Fuel cells (FC) are widely regarded as one cornerstone in the decarbonization of commercial vehicles. They offer carbon- and emission-free mobility in combination with short refueling times and high range. Due to the large variety of application of commercial vehicles – from light commercial to heavy-duty and long haul – a wide range of necessary powertrain power is required. For early market competitiveness and to cope with the large power range, fuel cell systems are often designed in a modular fashion for cost reduction. Besides low system costs, the pressure on development times and costs is equally high, making an efficient development process inevitable. For these reasons a wholistic model-based design process is presented to derive specifications and requirements, select, and optimize components for the fuel cell system (FCS) as well as powertrain and to optimize the control functions of the fuel cell system and hybrid system.

The model-based design process is based on the commonly known V-Model. This approach is characterized by multiple phases starting with the requirements and concepts until the final tests and system validation. Through a decomposition into sub-system and component layers, coupled with frontloading of validation activities via modelling, a large reduction in development effort and time is achieved. Such a process imposes several requirements on the modelling framework. The multiple tasks from requirements definition over component and system optimization to validation via model-in-the-loop assumes a flexible modelling approach where models can easily be exchanged in terms of their fidelity and physical approach. This is achieved via a common framework and universal interfaces. Furthermore, the model must provide suitable interfaces for the function development of the fuel cell vehicle and system. An overview of such a framework is depicted in Fig. 1. The model framework consists of multiple levels. The highest level are the supervisory control units such as the operating strategy and energy optimization. One level deeper the local control units for the battery management system, fuel cell controller, e-motor controller, and so on are located. On powertrain topology level, the subsystems of the powertrain are located, which naturally consist of several component models. All these layers are coupled with models for the vehicle, driver as well as target road profiles.

For the demonstration of the model-based development process a heavy-duty truck application is chosen. The use-case is a 4x2 rigid truck with an optional trailer, which is crossing the Alps on a regular basis. The design process is used to derive the requirements for the fuel cell electric powertrain and to size its main components, i.e., fuel cell system, battery, and traction motor. Through an analysis of the target route, using a high-level drive cycle calculation, the power and energy requirements can be derived. It was found that a fuel cell system net power of 150 kW is sufficient for continuous driving up to moderate road grades. For hill climbing and acceleration an optimal traction motor power output of continuously 350 kw is suitable for the use-case application. To fill the power supply gap between the fuel cell system and peak power requirement from the traction motor a battery is used. From the high-level drive cycle assessment, a final battery size of 73.2 kWh with a usable state of charge (SOC) window from 35- 70 % was selected.

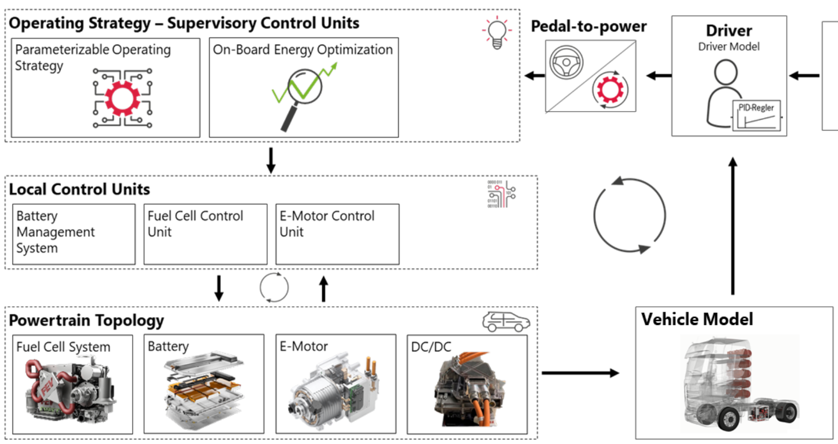

Fig. 1: Fuel cell heavy duty truck powertrain simulation framework

Reviewing the results of the final powertrain simulation, including a detailed fuel cell system model, the truck without trailer was able to complete the cycle with satisfactory performance and a hydrogen consumption of approx. 7 kg_{H2}/100 km. When the truck and trailer was considered, the performance was insufficient using the simple hybrid strategy with an SOC target of 55%. Through the implementation of a predictive operating strategy, the vehicle was able to complete the cycle with good performance.

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