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A modular fuel cell battery hybrid propulsion system for powering small utility vehicles

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Executive Summary

To improve the quality of life for citizens, development of standards regarding noise and exhaust emissions is essential. Thus, utility vehicles deployed by municipal operators have to fulfill these regulations. The project ELAAN, presented here, addresses this challenge by developing a fully electric propulsion system eliminating noise and exhaust emissions almost completely. The propulsion system uses a combination of hydrogen fed Polymer Electrolyte Membrane Fuel Fell (PEMFC) systems and lithium ion battery modules. These components follow a modular approach, which makes adoption of the modules for additional applications, such as the material handling sector possible.

Within the project ELAAN, fuel cell and battery modules are combined with an electric motor to power a utility vehicle LADOG T1250 which is often used in municipal applications. Conventionally, the vehicle is powered by a four cylinder diesel engine which feeds a hydraulic pump. As fuel cells, batteries and electric motor replace the diesel engine and hydraulic traction system, the fuel economy can be improved by a factor of approximately three. Hydrogen is stored at 350 bar and can be refilled within few minutes. This makes the use of the electric vehicle comparable with the conventional one in terms of operation and refill time.

Research and development activities within this project include analysis of the power and energy requirements, development of the electric motor, fuel cell system and battery module, integration of the components into the vehicle as well as accompanying modelling of fuel cell and battery in order to improve the system layout and operating method.

1 Introduction

Utility vehicles as well as other vehicles have to fulfill stricter emission standards. Additionally, noise emissions can lead to access restrictions within areas of high population density. The project ELAAN addresses this issue by providing a fully electric propulsion system consisting of fuel cell systems, battery modules and an electric motor. The novelty of this modular approach lies in its flexibility to broaden possible applications. Beside the realization described here, powering a municipal utility vehicle which is displayed in figure 1, the propulsion system can also be used for material handling applications. Therefore a system voltage of 80V is used. Due to the short refueling time, fuel cell based power systems for material handling applications are quite successful especially in the United States where more than 9000 devices have been delivered since 2009 [1]. There are also first applications in Germany at BMW, Mercedes und Hoppecke [2] just to mention a few.

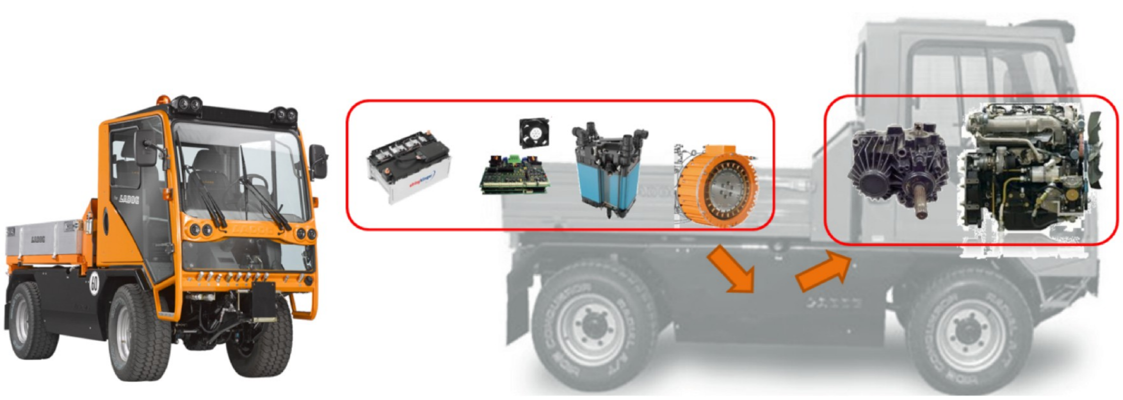

Figure 1: Vehicle LADOG T1250: Replacement of the Internal combustion engine and hydrostatic propulsion system by a fuel cell battery hybrid system

2 System topology

Data derived from the conventionally powered LADOG vehicle while driving a reference cycle was used to extract the power and energy demand. Findings suggest that typical driving patterns require an average mechanical power of approx. 20 kW while peak demand is in the range of 60 kW. Therefore the electric propulsion system consists of two fuel cell systems each providing 10 kWel. Peak power demand up to 60 kWel is provided by the battery pack. Nominal system voltage is 80 V. Advantages of this unique setup combining low voltage and high modularization include a high safety level due to the relatively low voltage and interconnection with other applications. For example, a half LADOG drive system with a continuous / peak power of 10/30 kWel fulfills the performance requirements of a class 1 forklift truck. Essential components of the tank system can also be used in other applications due to the selected pressure level of 350 bar. The battery pack is directly connected to the drive converters of the electric motor. The two fuel cells are connected in parallel to the battery modules via dedicated buck-boost converters. Thus, an active management of the power distribution can be realized.

3 Components of the propulsion system

3.1 Electric Motor

Based on an existing design, the electric motor was specially developed for use in this project. It is a liquid-cooled, permanent-magnet synchronous motor designed for a nominal output of 60 kWel at a nominal voltage of 80 V. A unique feature of this motor is the separation of the stator windings into three equal segments. This makes it possible to use three standard motor controllers as each controller only has to carry one third of the total current. Together with a two-stage transmission, the engine is installed on the rear axle. The front axle is driven via a cardan shaft.

3.2 Battery module

Each battery module consists of 7 series-connected prismatic cells in PHEV 2 format and has a nominal capacity of 945 Whel. Within the modules, the individual cells are connected via laser welded contacts. Cooling, temperature measurement and single-cell voltage detection are integrated into each module. In the ELAAN project, a battery pack consisting of twelve modules is used, so that a capacity of approx. 11 kWhel is available. The arrangement of three serial blocks with four parallel-connected modules results in the required voltage level of approx. 80 V with a maximum discharge power of more than 60 kW. The development work is accompanied by characterization of both cells and modules under various climatic conditions and at different load points.

3.3 Fuel cell system

Two parallel-connected fuel cell systems serve the basic load of the LADOG vehicle. Figure 2 shows the simplified schematic representation of such a system in addition to the real fuel cell stack. The central component forms the fuel cell stack, which consists of 100 individual cells. With dimensions of approx. 243 x 161 x 152 mm³, it delivers an output of approx. 13 kWel. Frost starts with this fuel cell platform have already been successfully carried out down to -20 ° C. Furthermore durability could be proven by the manufacturer: A 20-cell fuel cell stack has been operated for almost 8000 hours at different load stages.

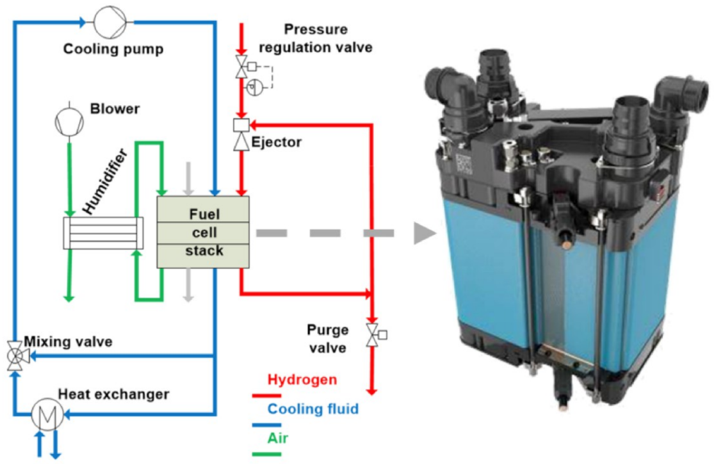

Figure 2: Schematic representation of the fuel cell system and photo of the used fuel cell stack with integrated media supply module

4 Accompanying model

By modeling the fuel cell system, different operating strategies can be tested simultaneously. For this purpose, models for the system components displayed in figure 2 are created and adapted to measurement data or data sheet information.

The fuel cell model itself is implemented on the basis of a liquid cooled fuel cell and includes mass transport balances, energy balances and electrochemistry. In order to consider dynamic processes sufficiently, heat transport mechanisms are differentially calculated, since they have the greatest time constants by far. The electrical current, operating temperature and volume flow of the entering cooling medium, relative humidity, pressure and temperature of the incoming gases at the anode (hydrogen) and cathode (air) as well as the ambient temperature are used as input data for the fuel cell model. The cell voltage and all output quantities of the material flows are calculated.

To model the battery, current circuit models are used. They are the most common type of battery modeling since they represent a good compromise between the accuracy of the electrochemical process and the time spent on implementation.

The electrical characteristic of the battery is transferred to mathematical equations by means of an equivalent electrical circuit constructed from discrete elements. The selected components comprise a voltage source dependent on different parameters for modeling the open circuit voltage, an internal resistor and two RC elements, which represent the dynamic processes in the battery.

Acknowledgments

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Stefan Keller is a diploma engineer for electrical engineering. He also holds a Master of Science in Sustainable Energy Competence SENCE and works as project leader in the department fuel cell systems of the Fraunhofer Institute for Solar Energy Systems ISE. His research focus is on stack characterization, modeling and system design.