EVS24
Stavanger, Norway, May 13-16, 2009

The new Audi Q5 HFC

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Abstract

In this publication we present the Audi Q5 HFC (hybrid / hydrogen fuel cell vehicle). These vehicles are based on the Audi midsize SUV Q5 with an in-house developed fuel cell system, employing a Li-ion traction battery and gaseous hydrogen stored at 700 bar.

The vehicles represent the next step in our continuous development of fuel cell vehicles. At the same time it employs as many components as possible also being employed by other fuel cell vehicles as well as conventional hybrid vehicles being developed within the Volkswagen Group / Audi.

Focus of the design was still on system development. As a result, several areas important for daily used are not necessarily optimised, as an example the driving range is not yet at a level which is acceptable for daily use. Yet cold start capabilities have been significantly increased, allowing for operation of the vehicle under normal winter conditions, with true cold starts as low as -15°C.

The vehicles are currently being employed at the California fuel cell partnership, were they are also collecting valuable data for the further optimisation of both the fuel cell system as well as the energy management of the hybridisation. After this stint the vehicles are slated to be used in Europe for further development and public presentation / demonstration.

Keywords: electric drive, fuel cell vehicle, passenger car, vehicle performance, ZEV

1 Introduction

Early 2004 Audi presented, on the basis of the Audi A2, its first generation of in-house developed fuel cell vehicles, the Audi $A2H_2s$ [1]-[3]. A picture of one, taken during the 2004 Michelin Challenge Bibendum, is shown in Figure 1.

At that time we were among the first to combine a NiMH-based traction battery with a fuel cell, making the $A2H_2s$ true hybrids. Being the only fuel cell car achieving only A and B-grades at the 2004 Michelin Challenge Bibendum in Shanghai [4] the usefulness of this concept was clearly demonstrated.

Apart from participating in the Challenge Bibendum, the $A2H_2s$ also served within the California Fuel Cell Partnership, see Figure 2. Allowing us to perform valuable data collection in non-European environments (especially higher temperatures combined with operation at higher altitudes). One of the cars is actually still serving at the partnership indicting the robustness of the system.

Figure 1 $A2H_2$ in front of the F1-Circuit of Shanghai.

Figure 2 $A2H_2$ in front of the capitol of California (at Sacramento).

Sticking to its nature of a prototype research vehicle, the $A2H_2$-family of cars is capable of driving in an all battery mode. As such, it is equipped with an integrated battery charging capability [1], making it a plug-in hybrid fuel cell vehicle.

Since the focus of this vehicle family was on learning the basics of the integration of a fuel cell system with a traction battery inside an Audi, the system was equipped with a Ballard HY80-Modul, also employed by other OEMs such as Daimler in its FCell4 and Ford in the Focus FCEV.

Due to the nature of research on the integration of the technique, the $A2H_2$-family of cars has a rather limited range of 220 km (based on the European driving cycle).

On the basis of the results obtained with the $A2H_2$s, as well as with other fuel cell vehicles operated within the Volkswagen group, we've developed the Audi Q5 HFC (with HFC standing for both **h**ybrid **f**uel **c**ell as well as **h**ydrogen **f**uel **c**ell) family. These vehicles are based on the new Audi compact SUV Q5, a picture of which is shown in Figure 3.

Figure 3 Audi Q5.

Contrary to the $A2H_2$-Family, these cars employ an in house developed fuel cell system. The fuel cell itself is, however, still bought from Ballard. The same system lays the basis for the Volkswagen Caddy HyMotion vehicles.
Inline with the increase of practical usage value, the system is designed to be freeze capable, having demonstrated to be able to start from - 15°C and a hydrogen storage pressure of 700 bar.

2 Vehicle and system description

2.1 Audi Q5

The Audi Q5 represents the mid size SUV from Audi currently being brought to the market. In its standard design, it is equipped with Audi's permanent all-wheel drive concept quattro.
Due to its high wheel base it is predestined for usage in alternative propulsion such as fuel cell.

A conventionally propelled hybrid version of the Q5 is due to come to the market soon. The system and component layout for this line of vehicles builds as far as possible the basis for the Q5 HFC, which consequently is being equipped with a number of the same components also being slated to be used in the Q5 Hybrid. Prime example being the traction battery which is a lithium-ion (Li-Ion) based system delivered by Sanyo (details see Section 2.2.3).

2.2 System

A schematic of the location of the different components is shown in Figure 4. More details on these components are given in the subsequent sections.
A table with a summary of the most important parameters is given at the end of this section.

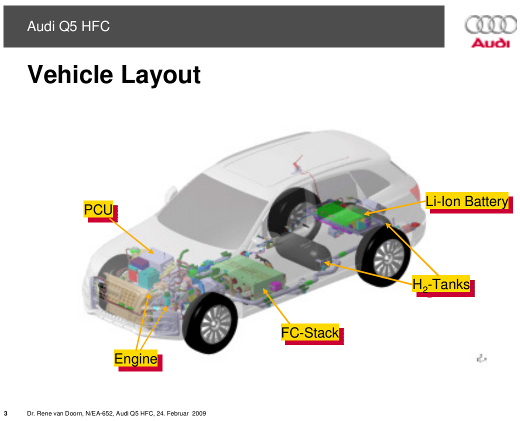

Figure 4 Vehicle layout.

2.2.1 Power grid layout

A schematic of the power grid layout is shown in Figure 5.
The tri-port DC/DC-Converter with build-in charger for the traction battery used in the $A2H_2$ [1], [2] has been abandoned for a much simpler design employing only a DC/DC-converter between the fuel cell system and the traction battery. Also a commercial available 14V DC/DC-converter, rather than one integrated within the power DC/DC-converter has been employed. The only non-conventionality in the system layout is the use of two rather than only one power control unit (**PCU**) for the engines. Details on this aspect are given in section 2.2.4.

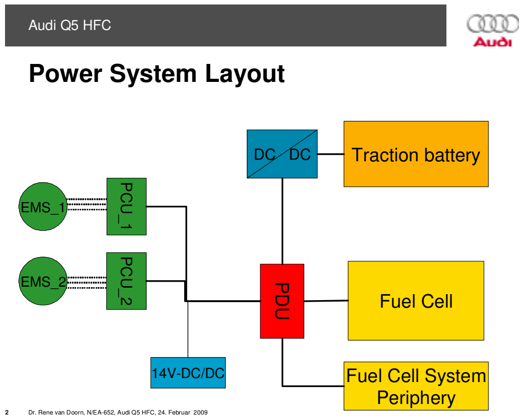

Figure 5 Power grid layout.

2.2.2 Fuel Cell System

The core of the fuel cell system is a Ballard Mark 1100 fuel cell stack. The complete periphery has been designed in house at the Volkswagen group. Due to its modular design the fuel cell system is also being employed in slightly modified layouts for other fuel cell cars such as the Volkswagen Caddy HyMotion.
This concept allows us to use the same modular groups, such as: air supply, hydrogen supply. With only mild modifications in the layout we are able to still use the same controls, periphery etc. and as such quickly adapt the fuel cell system to different cars. This is a property which is employed within the Volkswagen group on a routine basis for its modular building blocks approach, allowing us to employ for instance braking systems within different cars of the group.

2.2.3 Traction battery

The traction battery is a prototype version of the same traction battery to be used in the Audi Q5 hybrid. It is an air cooled Li-Ion battery made by Sanyo with an energy content of 1.4 kWh and a peak power of 37 kW. Conditioned cooling air is being taken from the interior of the Q5 HFC. The cooling air is being ducted out of the car in the rear axle area (see Figure 6).

The role of the traction battery is twofold. Its main purpose is of course the use as a hybridisation battery, as was shown so successfully in the $A2H_2$s. The second purpose is provision of the start energy of the fuel cell system.
Based on the experiences with the $A2H_2$s we have omitted the option to drive the car as a battery electric vehicle. This is also in line with the limited depth of discharge that the Li-ion battery allows.

2.2.4 Propulsion

As the propulsion system two wheel hub based synchronous E-Maschines are being used. To prevent the disadvantages induced by the weight of the engines in the wheel, both are placed back to back around the (0,0,0) point of the engine. No mechanical connection between the two engines is present. As a result the car has a virtual differential and a high level of strain on the controls.
These engines are commercial available, however, due to issues with the maximum allowable constant current, each engine is equipped with two PCUs rather than one. Due to package restrictions, as a result of space constrain, we were forced to abandon the concept of integrated engine and PCU as being employed in the A2H_2s.
At the relevant power level of 300 V both engines have a peak power of 45 kW_{mech} and a peak torque of 210 Nm up to the rotational frequency of 2050 rpm. Both engines are equipped with a reduction gear with a 4,94:1 ratio.
The engines in Audi Q5 HFC allow for a 0-100 km/h sprint of just 13 seconds and an electrically limited top speed of 160 km/h.

2.2.5 Hydrogen Storage

The main focus for the hydrogen storage system was to gain additional experience in the storage and safe handling of 700 bar gaseous hydrogen. As a result, we have placed the hydrogen cylinders in a crash safe position in the car around the rear axle. However, due to the space needed for the trapezium control arm of this axle limited space for the cylinders is available. Therefore, we were only able to place two standard Dynetek type 3 cylinders with a total of 3.2 kg of hydrogen in the vehicle.

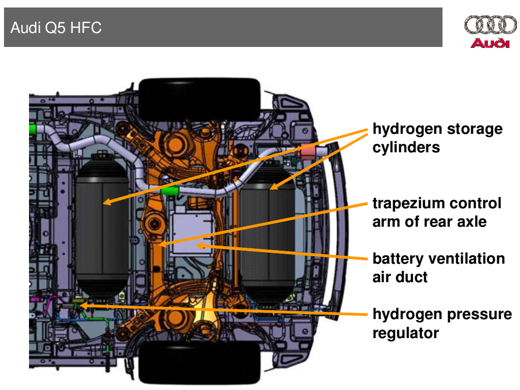

Figure 6 Hydrogen storage system.

The 3.2 kg of hydrogen in the current system layout with a scroll air compressor allows us a driving range of around 250 km on the basis of the European driving cycle.
As already mentioned we employed a standard car, which was not purpose designed for alternative propulsion, nor was gaseous fuel storage part of the design requirements for the Q5. In a series fuel cell car this would obviously be the case, and the limited driving range of the current car would be significantly be increased to at least the same range of a conventional gasoline powered Q5.

2.3 Overview

A summary of the most important parameters of the Audi Q5 HFC is given in Table 1.

Table 1 Overview

Hydrogen	Gaseous 3.2 kg 700 bar
Fuel Cell	Direct Hydrogen Ballard Mark 1100
Battery	Li-Ion Sanyo 1.4 kWh 37 kW Air cooled
Engine	2 * wheel hub like each with: 45 kW_{Mech} peak 210 Nm peak
V_{Max}	160 km/h (electrically limited)
Acceleration	0 – 100 km/h in 13.4 s 60 – 120 km/h
Driving range	~ 250 km

3 Next steps

The cars are currently being operated within the framework of the California Fuel Cell Partnership in Sacramento. Here we test the vehicles and optimise their performance with respect daily use in moderate to high ambient temperatures.
After these stints the vehicles will be operated within the Clean Energy Partnership in Berlin (Germany). Here we will focus our attention in more detail on optimisation of the overall system efficiency. One of the main subjects will be minimization of system parasitics such as the air compressor, which has been shown to be the major parasitic loss in the system. However, also the optimisation of the hybrid operation strategy as

well as cold temperature operation will be in our focus.

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