Dynamic Behaviour of a Fuel Cell with Ultra Capacitor Peak Power Assistance for a Light Vehicle

Jörg Folchert, Dietrich Naunin, Sina Block

Abstract

The operation of a Fuel Cell inside of a vehicle is a big challenge for control and safety. In continuation of an former project at the Berlin University of Technology a feasibility study for the use of a Fuel Cell in a light vehicle (TWIKE) was issued and realized. The Fuel Cell of this project (≤2 kW) is redesigned and will be provided with the necessary control and service structure.
A Fuel Cell needs for best efficiency an operating point nearby 70%-80% of maximum power, that means an almost steady power output. For this reason the Fuel Cell will get an additional power booster at the base of Ultra Capacitors for power demands during acceleration. These modules will be optimized for a light vehicle under the aspect of the dynamic behaviour and of the size/cost of the booster.
This Paper will give a detailed description of the Fuel Cell / Ultra Capacitor Booster and describe the first results of the dynamic performance of this system. *Copyright© 2002 EVS19*

Keywords: Converter, Fuel Cell, Ultra Capacitor, PAS (Power Assist Systems), PEM (Proton Exchange Membrane).

1. Introduction

An interdisciplinary project with the intension of equipping a TWIKE lightweight electric vehicle with a fuel cell started at the Technical University of Berlin in April 2001. The PEM fuel cell from the company "Sachsenring" was designed to replace one of the batteries. The PEM fuel cell has a maximum power output of 2 kW at 24 V. This voltage is converted to 400 V by a specially developed DC/DC-converter to power the motor controller and to recharge the 336 V battery module of the vehicle. The final version was planned to extend the driving range of the vehicle from 80 km to more than 250 km.
In continuation of this project a fuel cell test bench for the measuring of pressure, temperature, voltage, current and humidity of the fuel cell stack was developed (figure 1). With the test bench it is possible to research the dynamic and the efficiency behaviour of the fuel cell. This leads to Closed Loop Control algorithms for fuel cell operating at different stable working points. Therefore a new stack was provided.

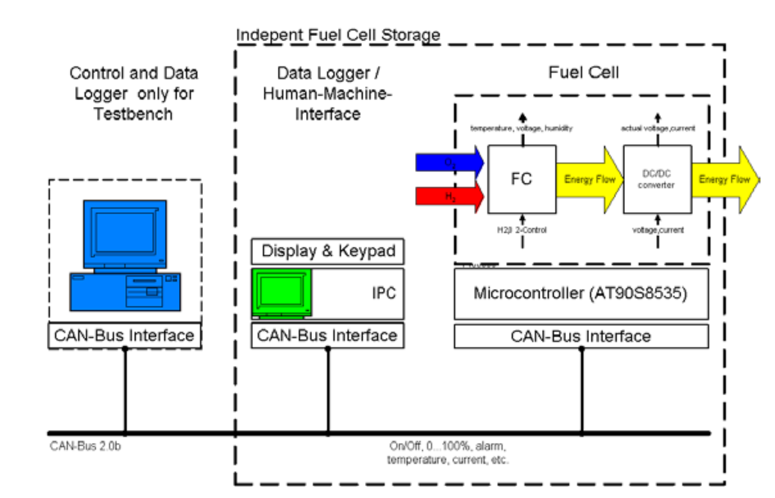

Figure 1: Structure of the Fuel Cell test bench

The first step of this project was to build up a new fuel cell stack and to equip it with the necessary periphery for operation control (fan, humidity supply, sensors, valves etc.). With a laboratory test bench (depending on a PC-System) first research results of the dynamic and the efficiency have been reached (shown in chapter 3).
The second step is to develop the Fuel Cell test bench to an independent power supply unit with a cooling system (including heat / humidity exchanger).
The last step before integrating the

system into the vehicle will be the EMC and crash safety tests.
By implementing the fuel cell into an electric vehicle the dynamic behaviour of the fuel cell will cause some problems if peak power is needed for acceleration. Ultra capacitors could level the power output of the fuel cell.
Therefore some dynamic tests with the fuel cell and an ultra capacitor (UC) booster are planned.

2. Concept of the fuel cell test bench

Hydrogen of high purity (5.0) and a pressure of 50 mbar is needed at the anode. It is provided from a gas bottle with 200 bar and flows over a pressure reducer. To the cathode flows ambient air, which is brought into the fuel cell by a fan. During operation humidity and pressure of the outcoming air, pressure at the cathode, temperatures at the stack, current and up to 10 voltages are measured.
The fuel cell is controlled by a microcontroller (figure 1). The sensor data are transferred to a computer by a CAN-Bus Interface. Over the same interface the control instructions for the FC will be sent back to the microcontroller. The load management of the FC is realized by a Step Down Converter which limits the current output depending on the operation values of the FC temperature and the FC voltage.

2.1. Hardware structure

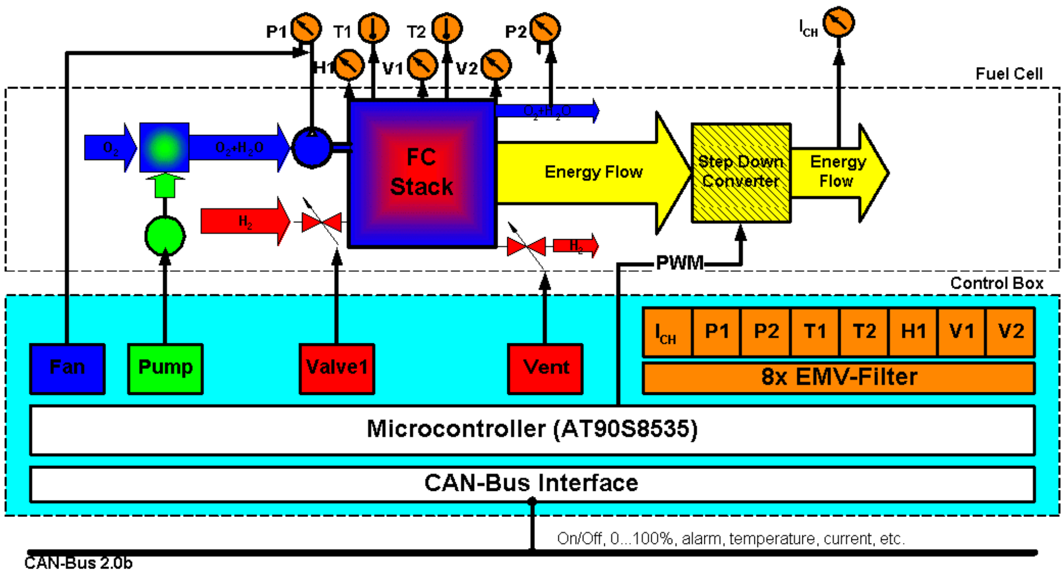

Figure 2: Structure of the Fuel Cell hardware periphery

In the test bench (figure 2) all data are measured by the microcontroller (2x temperatures, 2x pressure, 1x current, 1x humidity and up to 10 different module voltages) and will be sent to a PC which sends back the control values to the fan (PWM), pump (PWM), valves (On/Off) and Step Down Converter (PWM). All data will be saved and analysed (Data Logging). First dynamic tests and efficiency diagrams could be realized.

2.2 Descriptions of the Fuel cell power unit

In the second step (mobile power supply) the PC-task data logging and visualization will be handled by an integrated Embedded System PC (IPC). The FC control task will be solved completely by the microcontroller. By this way an independent FC power unit will be generated, which could be used universally.

2.3. Software

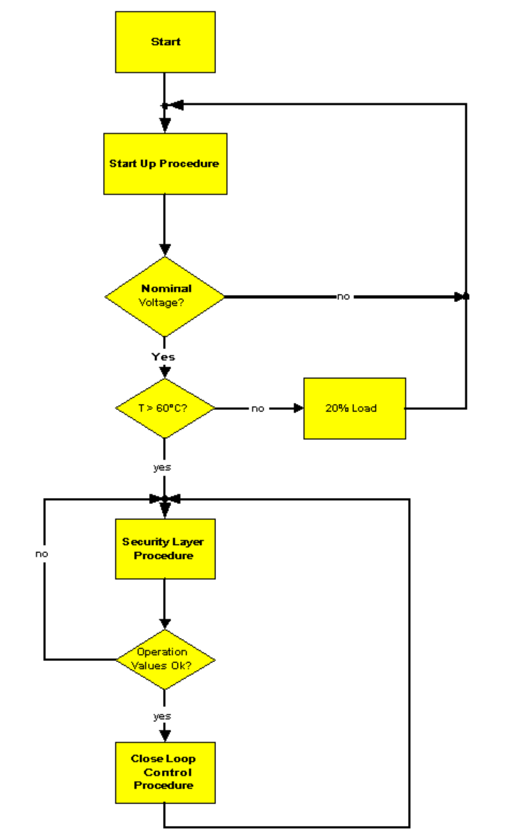

Figure 3: Software structure Fuel Cell

There exist different software tasks: first the Start Up of the FC stack, second the security layer, third the shut down of the stack and last the Closed Loop Control.

In the Start Up procedure the stack has no load until the secondary voltage is reached. Then it gets only 20% of the full load until the optimum temperature is reached.

The task of the security layer is the control of the stack in a way that no critical limits are reached.

The shutdown process is needed for a controlled stop of the fuel cell.

In the Closed Loop Control Procedure the user can specify several working points, which the software tries to reach under the aspect of stack safety.

The software algorithm of the Closed Loop Control task has to regulate power output at the best possible efficiency point of the FC. The control parameter are temperature (depending on the fan output), humidity (depending on the pump output) and power output (depending on the Step Down Converter). The best efficiency will be near the 70%-80% of the maximum power at continuous power output.

3. Implementation of the UC booster

The first results of the FC test bench are shown in the Current-Voltage-Power-Diagram of a 5 cell FC (Figure 4). This behaviour is transferable to a FC stack with more modules if the used cell type is the same. This diagram leads to an equivalent circuit diagram of the FC in which the FC is represented by a capacitor with a response time of about 1/8 sec.

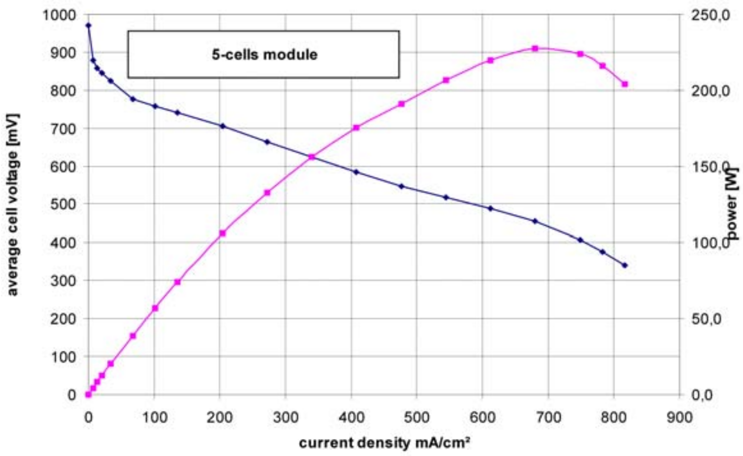

Figure 4: Current-Voltage-Power diagram of a FC with 5 cell

The results of an application of this model into a simulation program for the entire system is shown in figure 5. The FC has to handle a 200A load (red line). The simulation meets the behaviour of a real FC by responding each load pulse by a jump to the related Voltage-Power-Point.

With this simulation model first estimations of the dynamic behaviour of a FC unit are possible.

An FC unit used in an EV has to carry several power peaks (e.g. during the acceleration

phase) and normal power loads (drive load, uphill loads etc.). Figure 5 can be interpreted as a possible behaviour of a FC of an EV with a pulsating load, too.
This behaviour with high voltage steps causes additional problems for the vehicle because it leads to a wide voltage operation range. Wide voltage ranges cause in normal cases high losses in the motor (less efficiency areas). One solution is the use of Ultra Capacitor (UC) storages for peak power assistance (PAS).

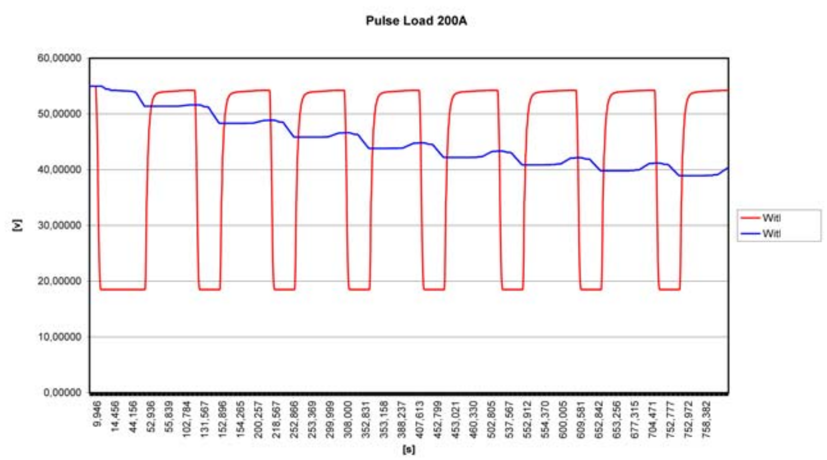

Figure 5: 200A pulsed load of a FC and a FC&UC

The simulated behaviour of a combined Fuel Cell and Ultra Capacitor storage system (FC&UC) is shown in figure 5, too (blue line). The voltage steps are smooth and only a slow voltage reduction is cognizable although there is an over load of 11 kW. The dimension of the UC storage depends on the nominal resp. peak power load and on the voltage range (efficiency range) of the motor.

Figure 6 shows the structure of a possible combination of a FC and a UC. The FC unit described in figure 1 is replaced by the FC&UC unit shown in figure 6. The UC part has its own microcontroller and CAN-Bus interface and is completely independent of the FC part. It provides besides a medium power supply (based at a DC/DC Converter) an additional connector for peak power assistance. The CAN-Bus is only needed for the communication between the FC and the vehicle management unit (VMU) resp. between the UC and the VMU. It contains only the reference values and the visualizations data.

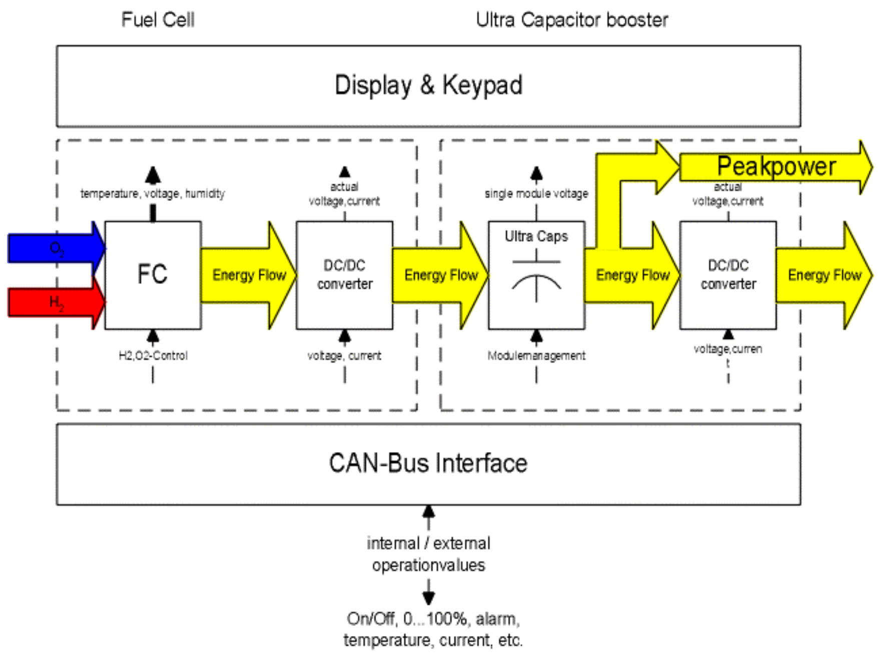

Figure 6: Fuel Cell with control structure and Ultra Capacitor booster

For detailed descriptions of the UC storage system please refer [1]. The complete system will be built up in the next future and the first data will be presented at the poster session at EVS 19 in Busan.

4. Conclusion

The power requirement of an EV includes besides of the normal drive conditions (drive load, uphill drive loads) peak power loads like acceleration power. It was shown that a normal dimensioned Fuel Cell is not able to supply these peak power assistance. A cost effective solution will be the combination of a Fuel Cell with a peak power UC storage.
The Fuel Cell unit and the UC storage [1] is described in detail and will be operated in the next future. The results of the dynamic tests will be presented at the EVS19.

5. References

[1] Ultra Capacitor Storages for Automotive Applications, EVS19, Jörg Folchert, Dietrich Naunin

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