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Sub Kilowatt Fuel Cell Systems – Solutions for Applications

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1 Introduction

Development of fuel cell stacks and its components is a core topic for R&D and industry. Fuel cell development has to go hand in hand with optimisation of supplying peripheral components and controls. At ZBT the work is focussed on small PEM fuel cells (LT & HT) and their systems, specialising on stack and system development in the range between 100 W and 1.000 W, hydrogen or reformate powered.

Fuel cell systems in the sub kilowatt range serve numerous possible applications. With the described fuel cell stack technology system designs have been realized for different types of applications, eg.:

- Supplying electrical power for drives with high efficiencies of about 60 %,
- Supplying electrical power for small UPS devices with minimum startup times, very high power densities and wide range of tolerable environmental conditions
- Supplying oxygen reduced breathing air for simulated high altitude training of athletes
- Supplying autonomous electrical power for portable and leisure applications

In this paper the different strategies for exemplary system designs and controls are discussed and results of operation of the fuel cell stacks and the systems are presented. Focus of the development is always the solution for the application including all necessary testing routines for secure operation.

2 Fuel Cell Stack Technology

The fuel cell systems described within this paper are based on a hydrogen powered air cooled polymer electrolyte fuel cell stack (PEFC). The stack is a development of the research institute ZBT and is based on commercially available membrane electrode assemblies (MEA) and injection moulded graphite based bipolar plates with 50 cm^2 active area [1] [2], Figure 1. The core benefit of this plate production method is the significant reduction in the total production time for the plates and a constant high quality. Even at relatively small quantities of 500 plates the production process from raw material to pre-finished plate including flow fields and structures has been demonstrated to be less than 2 minutes per half-plate. This enables ZBT building up uniform stacks in sufficient volumes for R&D and demonstration purposes. The stack technology and the surrounding media supply and controls for various applications are available for power supply applications in the range of 200 W_{el} up to 750 W_{el} [3] [4] [5] if using air cooling. Systems using the liquid cooled stack setup can be constructed up to 1.2 kW_{el}. In Figure 2 exemplary the IV-curve of a 24 cell stack is shown.

Figure 1: 24 cell air cooled fuel cell stack / ZBT.

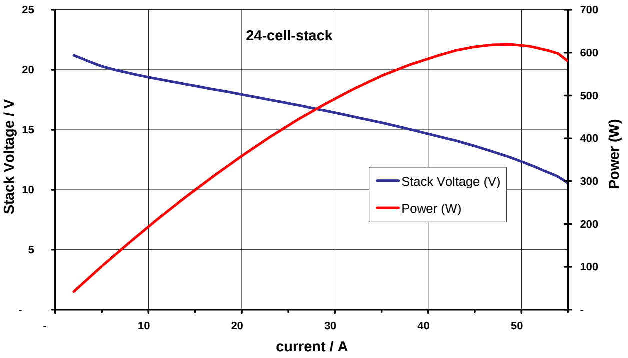

Figure 2: Voltage and current characteristics of a 24 cell stack.

3 Control Methodology

For fuel cell system setups a complex controller is needed to handle several system security requirements and for an optimal operation of the system. Simulation can be used to find the controller parameters and to test operation strategies. Interactions between the simulation and the real system are essential but complex. A close link between simulation and real system is important. The ZBT system simulation, programmed in Matlab/Simulink®, is divided into a model of the fuel cell system and a model of the controller. The controller model is enhanced with a blockset designed by Fraunhofer IIS [6]. It enables to generate the source code for the controller of the real fuel cell system, based on an "Atmega 128 microcontroller". Blocks for "digital IO", "analog in", "pulse width modulation out", RS232, SPI and I2C are added to the input and output. A master block is used to perform the necessary setup of the microcontroller. Finally the source code is build with the Simulink Real-Time Workshop® and is programmed directly to the microcontroller, Figure 3. This close relation allows an easy reciprocal enhancement of the real system, the simulation and the controller, Figure 4.

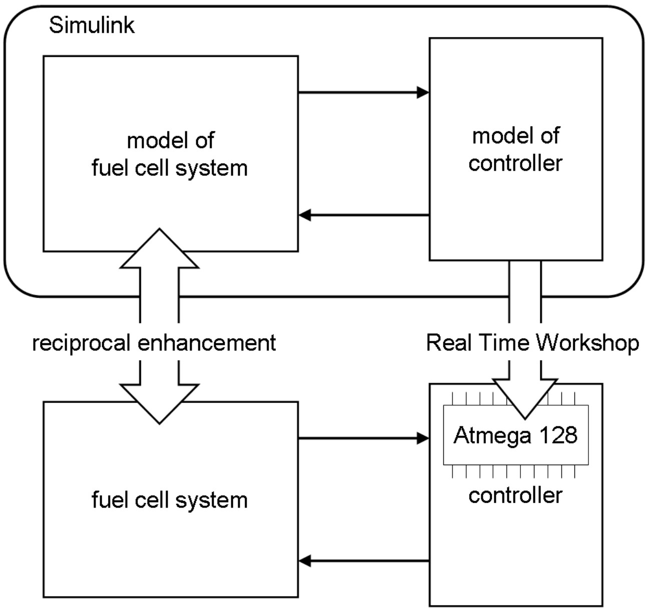

Figure 3: Interaction of simulation and real system.

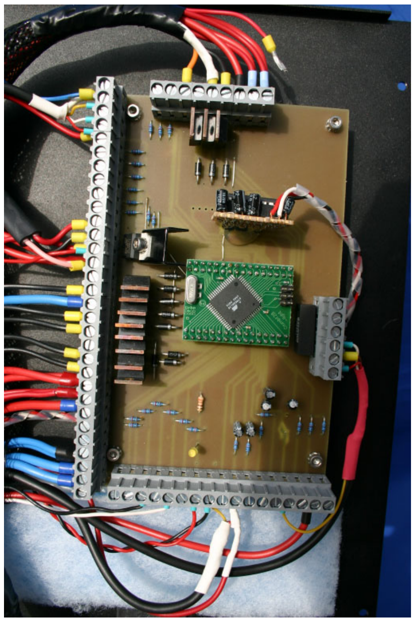

Figure 4: Developed controller board.

4 H_2 - Fuel Cell System Module

High efficiencies and low emissions make the fuel cell an interesting option for Auxiliary Power Units, APU. A couple of applications can take advantage of the short starting time and high dynamics of hydrogen powered fuel cell systems. Various system approaches have been designed for the special need of the specific application. The design of a modular system with very few and simple interfaces reduces that high effort to a minimum. The developed system (see Figure 5, 4) is based on the 19" standard, the system support is reduced to a hydrogen supply connection and a 24 V voltage supply.

Figure 5: Modular 500 W FC system.

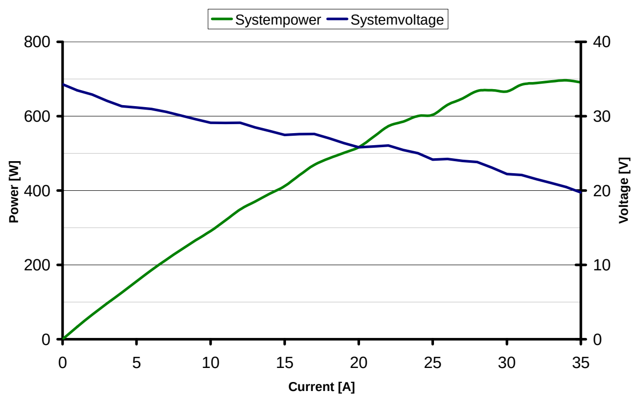

Figure 6: System voltage and performance curve.

The reason for the external supply of the necessary power for the peripheral components at 24 V_{DC} is that thereby the system does not need any additional storage devices such as batteries. The module is integrated into existing energy architectures which usually have storage devices or any form of starting voltage available. During fuel cell system operation the peripheral power can be served by the fuel cell system itself.

On the other hand the used approach to give the stack terminal power directly as output of the system module is a result of the experience of various system design projects performed. The individual application normally needs a special power conditioning module eg. for charge control of used batteries, serving special load voltages etc. Therefore it was decided to exclude this part out of the main system module and thereby increase the final system efficiency. Surely the stack is protected against reverse currents and short circuits by electric components.

The system design enables furthermore online analyses like electro chemical impedance spectroscopy and current interrupt method.

The technical data of the system module can be summarized by this:

- overall size: 483 x 230 x 300 mm (l/w/x/h)
- weight: approx. 17 kg
- air cooled stack with 38 cells
- hydrogen (3.0) / 2 - 6 bar_{abs}
- power supply periphery: 24 V_{DC}
- output voltage: 20 V - 35 V_{DC}
- power: 500 W / max: 750 W
- environment: 4 °C - 30 °C
- start time approx. 2 sec.
- analog and digital port (RS232)
- CE – approved

The modular system design enables an easy integration in other systems. The 19” body fits perfectly for telecommunication purposes and building services. The system provides the full power after just a few seconds and is ready for long-term usage. With an operating level of 24 V_{DC} and continuous power of 500 Watt there are several more applications which can be powered. Parallel connection of the modules is possible. For education, research and development the measurement data and operating parameters can be monitored via digital port.

Within a joint research project the Technical University of Chemnitz [7] integrates the described fuel cell system module into an autonomous transport system. Therefore a power electronics / super capacitor setup is attached and supervising energy management algorithms are being applied. The modular fuel cell system concept here allows to operate the system under the full control of the energy management but without any direct data connection to the fuel cell system controller, which acts individually reacting on the current demand of the attached power electronics.

5 H_2 - Application: Uninterrupted Power Supply (UPS)

Uninterrupted power supply systems (UPS) for telecommunication are already under discussion both for centralized applications as well as for decentralized applications. Remote repeater stations which have an electrical consumption of less than 750 W_{el} are more and more equipped with UPS systems based on either batteries or super capacitors. With decreasing reliability of electric mains the length of power outages is increasing. The more telecommunication is a necessary part of everyday life the more raises the demand for long term power backup of the telecommunication networks.

Using hydrogen powered fuel cells as long term energy source in addition to short term storage devices such as super capacitors is an environmentally and economically interesting option for decentralized backup systems. A solution for an outdoor cabinet integrated fuel cell powered UPS has been developed. The system architecture is optimized for traffic components but is already including the classic power supply technologies for telecommunication applications. The back-up power system contains a hydrogen powered fuel cell system, a UPS module and a supervising controller unit.

The 650 W_{el} stack is integrated into a highly developed system architecture which includes all necessary peripheral components (eg. pumps, valves, fans) as well as control electronics and routines. The control algorithms are developed fulfilling the demands of stationary independent fuel cell systems including e.g temperature management during operation and stand by and vital testing in times of non operation of the system. All components are integrated into standard 19’’ racks, using internal heat management.

Figure 7: System operation in Northern Sweden.

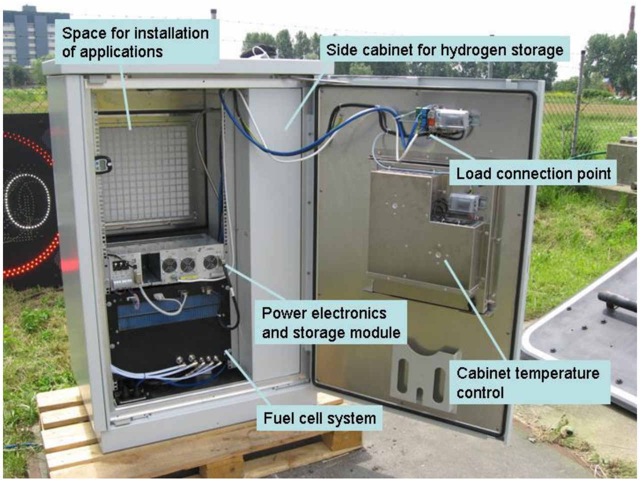

Figure 8: UPS operation in the Netherlands.

The UPS module is based on a DC/DC Converter and a capacitor block with double layer capacitors. A bidirectional DC/DC converter is connected to the internal 48V DC bus and is charging the capacitors when public mains are available. At mains failure the DC/DC converter is powering the 48 V DC bus by discharging the capacitors. Connected to the 48 V bus is the DC/AC converter powering the loads. The capacitor block is powering the start-up time of the fuel cell system and secures smooth system behaviour on any load changes and short time power peaks.

The described modular components (power electronics, capacitors, fuel cell system) are mounted into standard cabinets (see Figure 8) either for indoor or outdoor use. The double-walled outdoor cabinets include a tempering module for winter or summer use securing a rapid system start-up at any net outage. Using this approach typical outdoor temperature ranges from minus 40 °C to plus 45 °C can be served. The operation under freezing conditions was demonstrated during a one week field trial in Northern Sweden in January 2009 (see Figure 7) The cabinet also includes a separated storage cabin for standard 10 l_N 200 bar hydrogen bottles.

Application for this system architecture is the uninterrupted power supply of traffic control components as well as decentralized telecommunication devices. To increase the backup time of the standard UPS modules (power electronics and supercapacitors) they are now supported by the described fuel cell module. Average loads of up to 500 W_{el} can be securely powered by using this setup. On full load two standard bottles hydrogen (200 bar / 10 l_N) are able to supply energy for at least 8 hrs of operation which is more than regular mains failures least in the UCTE networks.

6 Conclusion

Applications for which fuel cells give the highest added value are situated in the field of auxiliary power units (APU) and other low power applications. In the range of 100 W_{el} up to 500 W_{el} (net power) the fuel cell research centre ZBT ("Zentrum für BrennstoffzellenTechnik gGmbH") recently has developed and demonstrated different hydrogen fuel cell based power supply layouts. These systems which include ZBT's air cooled APU-stack technology have been used for demonstration and application purposes for various applications in the field of decentralized electrical energy supply.

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