Guideline for the Investigation of PEM Fuel Cell Systems in Automotive Applications

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***Abstract*-In the context of a research project in the field of energy conversion and drive systems at the Otto-von-Guericke University Magdeburg, four proton exchange membrane (PEM) fuel cell systems of the newest generation have been put into operation. The investigations refer to stationary and mobile applications as well as to lifetime tests of the fuel cell. The plants are presented and scheduled measurements plus the research goals are described. The operational behaviour of the fuel cell and the overall system are evaluated for long-term investigations. A further emphasis is on the behavior of several fuel cells, which are operated with different gas compositions. Because the measurements are still in the early stages, the report mainly describes the project goals and gives an overview of fuel cell technology.**

I. Introduction

Both the conventional and the alternative energy industry are undergoing strong changes due to the intensive price fluctuations of fossil energy sources in the last few years [1]. The future global energy supply can be realized only by an increase in the amount renewable energy, in order to ensure a safe and stable energy supply in public and private life. Apart from the renewable energy from sun, wind, earth energy and biomass, hydrogen is another option, which through industrial or renewable processes makes it possible to convert chemical energy in fuel cells into electricity and use it at any time, independent of the volatile energy supply from alternative energy sources.

The electrical and thermal energy supply from the fuel hydrogen in fuel cells has already been successfully tested at research institutions and in the industry for over 20 years. The market introduction of fuel cell systems to the home energy supply or to the driving power in vehicles is, however, delayed. This delay is due to the current lack of a comprehensive hydrogen infrastructure and also because material problems with the electrolyte and the membrane of the fuel cell have not been solved yet.

In a research project in the field of automotives in a scientific instrumentation proposal of the German Research Foundation, four PEM fuel cell systems with an electrical power between 400W and 5000W are examined under different aspects and future areas of application of PEM fuel cells are tested. The measurements will begin fully in the spring of 2009.

II. Introducing of Fuel Cell Systems

The investigations are directed at four PEM fuel cell systems in the electric power range between 400 and 5000W. These are low-temperature fuel cells with a maximum operating temperature of 80°C on the primary water side. The high temperature PEM fuel cells work at temperatures of up to 180°C and have been tested only for a few years in the field of research [2]. The plants in this project, however, are not designed for this type of high temperature PEM fuel cells.

The fuel cell group consists of three systems with an electrical output in the range of 400-500W and one system with an output power of approximately 5kW of electric and 10kW of thermal power. Each plant is different in its procedural process structure and is used for various measurements and investigations. The three small plants are named the “Reformate”, “Hydrogen” and “Experimental” plants.

The reformate fuel cell system is operated with hydrogen from an electrolysis plant and carbon dioxide from pressure cylinders. The fuel composition is derived from the actual reforming of natural gas or biogas after the reforming stage. The real proportions of hydrogen and carbon dioxide through the reformation were measured by another fuel cell system with an integrated reformer. These measurements are now available for the simulated gas composition of the reformate plant. Depending on the efficiency of the reformer and electric power of the fuel cell, the proportions of hydrogen is at a maximum of 70% and carbon dioxide at 30%. This unit is designed for long-term studies in the stationary operation for the domestic energy supply. Both the fuel cell system as well as the components of the plant will be investigated after several thousand hours of operation. The hydrogen plant was developed with much more variability in its operation mode and operates with pure hydrogen from the electrolysis plant. Different modes of operation can be implemented, which can be used for different applications. For example a recirculation of unused hydrogen, which does not react at the membrane, is integrated by being pumped back to the inlet hydrogen channel of the fuel cell. The practical effect of recirculation on the fuel consumption and material compatibility of the pumps on the humid and heated hydrogen are an essential aspect of the investigations of this facility.

Figure 1. Fuel cell test benches”Reformate“,”Hydrogen“and “Experimental” (from right).

Another focus is the behaviour of the bipolar plates under various operating conditions. The bipolar plates form the gas channels through which the fuel and oxygen lead to the membrane, whereby hydrogen is on the anode side and oxygen of the ambient air is on the cathode side. The correct construction of these channels is responsible for low pressure drops and for an effective use of the air compressor. The air compressor has the largest energy consumption of the fuel cell system. The bipolar plates have been especially designed for each fuel cell system by the manufacturers. The test results of this new generation of bipolar plates and the use of a new membrane show development progress in this field. The hydrogen plant is suitable for investigations in the mobile and portable fields in which pure hydrogen and no gas compositions are used. The system will be tested in the range of auxiliary power units (APU) for automobiles and the possibilities will be explored for a reduction of fuel consumption through the use of a fuel cell.

The third plant is used for system optimization. Individual components are tested and developed with the goal of minimizing energy expenditure and simplifying and optimizing the management processes. The development work in this area should be introduced in the other plants, so that the entire system is improved in its efficiency.

The 5kW plant will be supplied with pure hydrogen from a tank reserve on the university campus. The main focus of this plant lies in the mobile application. The various modes of hydrogen management in the system and the ability of the moistening of the reaction gases to the optimal energy conversion at the cell membrane are the subject of investigations.

All four units are connected via a network and can be controlled in the laboratory as well as with remote access.

Figure 2. 5kW fuel cell facility for mobile tests.

III. Fuel Cell Research for Stationary Application

The power supply for households is being decided ever more strongly by decentralized energy installations directly at the site of the end customers. Solar systems, small wind turbines or wood pellet heating systems will find increased use in single and multi-family houses. In this application market, fuel cell systems offers a great potential as combined heat and power plants, to provide both the electrical and thermal energy. The prerequisites include 40,000 operating hours, low downtime, comparable costs in the range of existing home power systems, and the useful hydrogen production from renewable energy sources. However, an introduction to the market of such stationary fuel cell plants in private households is expected yet. At the moment different projects involving fuel cell plants are being used and tested in households by the end customers in their everyday employment [3].

The tests for stationary applications are based on load profile curves of single and multi-family houses. Load profiles are copied during a longer period. Here, the actual performance of the fuel cell is scaled down to the power in the household. From the result of several thousand operation hours, the achievement performance of the fuel cell and life time prognoses should be determined. Figure 3 shows the load profile of a single family house on one summer day at the weekend. From the existing data records, the fuel cell system can now be operated as a house power supply plant.

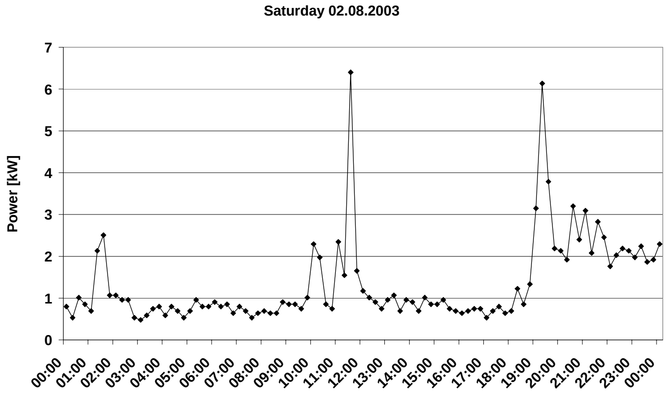
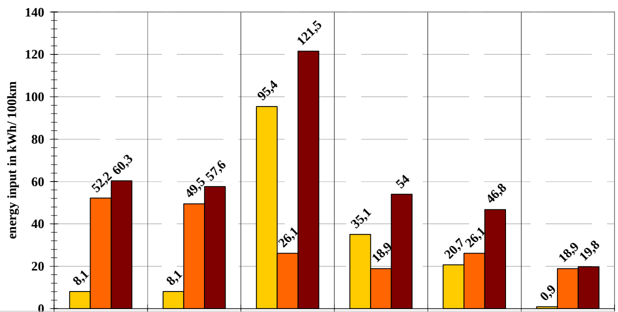


Figure 3. Load profile of a four person household [4].

IV. Fuel Cell Research for Mobile Application

The automobile and its different propulsion principles are undergoing great changes. The European Union calls for drastic reductions of emissions in the transport sector through new innovative drive concepts to ensure mobility and to be independent of limited fossil fuels. This can be achieved by more efficient engines, the integration of energy storage such as batteries to minimize the consumption and to reduce local emissions in hybrid vehicles as well as the long-term market conquest by fuel cell and electric vehicles. The battery technology of electric vehicles is not currently in a position to travel distances in excess of 100km, so this energy storage is used especially in urban areas. The fuel cell can travel distances of up to 300km using new storage technologies, like the 700 bar storage of gaseous hydrogen [6]. For example, fuel cell buses have already been driving in the public traffic for several years in Hamburg and Berlin.

Illustration 4 shows the energy expenditure for a distance of 100km for different engines, whose fuel originates from different energy resources. It can be clearly seen that fuel cell vehicles possess less energy expenditure than conventionally moved vehicles only during renewable hydrogen production.



engine	otto engine (DISI)	diesel engine (DICI)	electric engine (fuel cell)	electric engine (Li-Ion-battery)	electric engine (fuel cell)	electric engine (Li-Ion-battery)
fuel	benzine	diesel	pressured hydrogen	electricity	pressured hydrogen	electricity
process chain	production/ transportation/ refining	production/ transportation/ refining	power generation/ power gird/	power generation/ power gird/	power generation/ power gird/	power generation/ power gird/
energy resource	oil	oil	Eu-energy-mix	Eu-energy-mix	wind/ water/ sun	wind/ water/ sun

producer chain vehicle total

Figure 4. Energy expenditure of different engines and fuels [5].

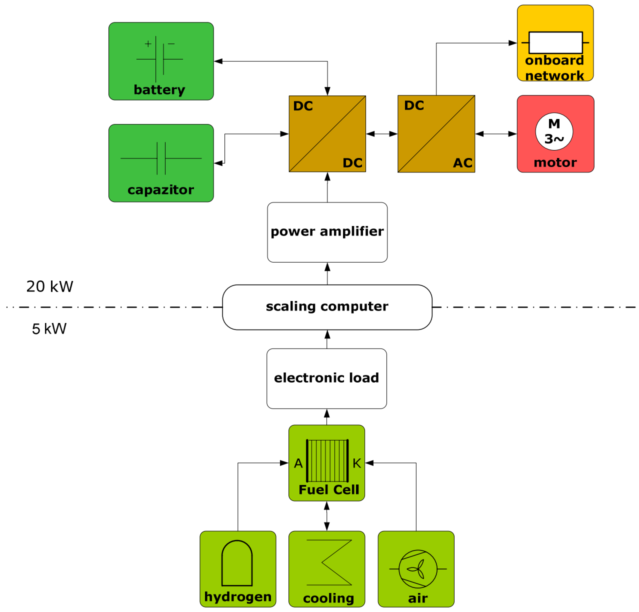


Figure 5. Scheme of the mobile fuel cell system [7].

The reason for this is that at the moment, the production of hydrogen is still energy-intensive. Battery vehicles exhibit in contrast smaller energy expenditure in the European energy mix and especially with regard to the renewable energy supply.

As previously stated, the 5kW system is used in the research project for mobile applications. Figure 5 shows the experimental scheme between the fuel cell and an electric motor. The energy of the fuel cell is delivered to a load and a scaling calculator increases the electric power of 5kW up to 20kW. The use of power electronics, inverters, electrical motor and storage systems such as batteries and super capacitors constitute the entire power train of a vehicle. The whole system is tested by driving cycles and the interaction of the different energy storages is investigated. During rapid load changes, the super-capacitors should guarantee the dynamics of energy supply.

V. Lifetime Prediction of Fuel Cell and Green Fuel

The lifetime of the fuel cell stack is the main criterion for the market launch of fuel cell systems for various applications. Also after 5,000 or 40,000 operation hours the electrical power output may decrease only insignificantly. The lifetime estimation can be accelerated by lifetime tests. This requires more stringent operating conditions. It should be noted, however, that the meaningfulness of such accelerated tests is limited, because key operating conditions such as downtime and its impact on the fuel cell will be not considered. In contrast, real operating conditions of several plants under realistic dynamic loads are more meaningful. A disadvantage is however the expenditure of time.

A combination of accelerated tests and the influence of key parameters and criteria that can only occur under real conditions will be introduced in the investigations. From these measurements lifetime curves arise for one type of fuel cell, depending on the design of bipolar plates and type of membrane used and other components. From the comparison of several fuel cells then prognoses for the lifetime and for influence parameters are to be identified.

A further influence parameter on the lifetime is the quality of the fuel and its composition. By using different gas compositions and humidity ratios influencing factors have to be identified and have to be integrated in lifetime forecasts. Above all, the quality of the fuel gas and its monitoring is an important aspect in these studies.

VI. CONCLUSION

This paper gives an overview of the future studies on four new PEM fuel cell systems for mobile and stationary applications. In addition to lifetime predictions and measurements in simulated fuel compositions, system optimization is also in the foreground. The results feed directly into the system optimization of fuel cell systems of project partners.

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