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SOFC in Dispersed Power Generation

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Abstract

Fuel cells are seen as a significant innovation for energy generation of the future since they are both environmentally friendly and can convert natural gas to electric current with comparatively high degrees of efficiency. Its introduction is especially suited for the decentralized provision of electricity and heat. The SOFC-technology is still at the beginning of its development, although a 100 kW-plant was already demonstrated using Westinghouse's tubular concept. The alternate to this, the planar SOFC is still in the development stages of units between 10 and 20 kW. Siemens wants to put a 50 kW-test plant for the planar system into operation next year. The introduction of high-temperature fuel cells will follow conventional combined heat and power plants (CHP) in competition. To be successful, competitive life-cycle costs are required. Hence, considerable efforts will be needed from the supplier in the coming year given the present position. © 1999 Published by Elsevier Science Limited. All rights reserved

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1 Introduction

During the last 10 years decentralized power generation plants, which bring the consumer both electricity and heat to the region of demand, became an interesting alternative for local and industrial consumers of energy, This is again reflected in the number of CHPs erected, which increased continuously at a rate of up to 180 plants per year until 1988. Today the increase is around 160 plants per year, which corresponds to an electrical output of approximately 70 MW a^{-1}. The liberalisation of the electricity market will probably lead to a further increase in the rate of growth. Also, the increasingly more powerful simultaneous exploitation of electricity and heat will increase the demand for small combined systems.

For this reason, at the beginning of the 90s, the development of high-temperature fuel cells started at Siemens. This was after a 2 year definitions phase in which all fuel cells relevant to power stations were investigated.

2 Technology of the SOFC

The Solid Oxide Fuel Cell, SOFC, is being developed world wide in two different concepts. The development started with the tubular concept which was, in particular, pursued by Westinghouse and also by Mitsubishi Heavy Industry, and was demonstrated with power of up to 100 kW. This technology is based on the fact that ceramic tubes are produced through extrusion, attached sintering, and coating. A method available for the ceramic-technology of that time. Only through the further development in production methods of ceramic construction parts will it be possible to develop a planar concept. This concept is being pursued in Europe by Siemens and Sulzer and in the past by Dornier. The principal function will be explained shortly as an example of this concept.

The solid oxide fuel cell uses, as the name suggests, a ceramic or more precisely an yttria stabilized zirconia as oxygen-transporting electrolyte. The electrolytes are produced with a thickness of approximately 150 μm and a surface area of $5\times5\,cm^2$ and $10\times10\,cm^2$. The ion-conductivity of the electrolytes appears at high temperatures over approximately 600°C. The electrolyte is coated on the fuel-side by an anode made of nickel–cermet, and on the air-side it is coated by a cathode made of lanthan–strontium–manganat. These electrodes act as catalysts for the chemical conversion of the fuel or oxygen in the 3-phase-boundary gas/electrode/electrolyte. The porosity of the electrodes amounts to about 40%. The electrode-coated electrolytes are, according to their function, fuel cells in a narrower sense, and are often called membrane electrode assemblies.

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The advantage of the SOFC is that at high temperatures natural gases too can be directly reformed and so not only hydrogen and carbon monoxide can be employed as fuel, but natural gas, in a mixture with steam, can also be directly electro-chemically converted in the cell.

Because of the high cost of mechanical plant components at a temperature of over 900°C, the development of high-temperature fuel cells is, in the meantime, moving to lower temperatures; i.e. between 800 and 900°C. Typical values of single cells for the planar concept are, for example at an operating temperature of 850°C and a voltage of 700 mV, more than 400 mA cm^{-2} current density in a hydrogen–steam mixture (1:1), which corresponds to a fuel-utilisation of 60%.

Hence power densities of about 0·3 W cm^{-2} can be achieved. The long-term stability of single cells has, under the above conditions, since been improved to 0·5%/1000 h voltage loss, which is also a sufficiently good value for a SOFC power station. Initial investigations with methane and internal reforming show that with about 10% pre-reforming, stable operation of the cells can be achieved and is consequently already being tested in bigger stack-units.

In the Siemens-concept even smaller MEAs of $50\times50\,mm^2$ are being joined together on big bipolar plates in arrangements of 4×4 units. Stacks of up to 80 planes have already been investigated. One of these gave a total power of over 10 kW when operated with hydrogen/oxygen. The further development involves $100\times100\,mm^2$ sized MEAs and a correspondingly bigger bipolar plate which can take nine cells. So far, such stacks have been successfully constructed and have been used to demonstrate that a thermal cycling is possible.

Based on the stack results, a test-stand for a 20 kW system was developed and built. This system has already been successfully tested with bigger test-units. The thermal and I&C properties of the test plants are currently being tested using dummy-stacks of up to 15 kW. From these investigations, the thermal losses have been further optimised. A 50 kW plant is being prepared for 1999.

3 Plant Technology

The fuel cell stack constitutes the centrepiece of the fuel cell plant. For a completed full-system there are, in addition to the fuel cells, further part-systems necessary for fuel cell preparation (e.g. desulpherization), air supply, beat exchanger for heat recuperation and heat supply, and for transformation of DC current to utilizable AC current for the net supply. Also, plant management is necessary.

The corresponding plant concepts are presently being tested in the above mentioned test-stands. The plant concepts are being optimised by a maximum electrical power supply to the grid. Hence an electrical efficiency of 51% is expected in the planar concept in an unpressurized operation for internal reforming and an operating temperature of 850°C. In using the surplus heat for district heating, for example, an efficiency of up to 93% is expected from the used energy.

An efficiency of 47% for the 100 kW-plant at full load was already demonstrated in the EDB/Elsam plant in The Netherlands.

4 SOFC for Decentralized Power Supply

A significant incentive for the introduction of the SOFC lies in the high efficiency relative to that of competitive power generation plants. About 50% net electrical efficiency is already being achieved by the 100 kW plant for unpressurized operation in the small power range. This efficiency for MW-plants can be increased to up to 70% through the combination of fuel cells with small gas turbines. In this case, however, the fuel cells must be operated at an excess pressure of approximately 10 bar.

A pressurized plant will be put into operation by Westinghouse in 1999 and so the proof of this will commence. This plant of 250 kW would already achieve an electrical efficiency of more than 60%.

These outstanding levels of efficiency cannot be achieved by conventional technology like gas engines, diesel engines, etc. Even larger diesel engines of quite some MW power never achieve more than 43% electrical efficiency. In the future less and less heat will be needed due to building management methods, but for this increasing amounts of electricity is needed—so the high temperature fuel cells fit in exactly with the right trend.

5 Market Introduction of SOFC Fuel Cells

In the view of the customer, a fuel cell must appear exactly like a conventional CHP, as a compact plant which will be supplied with natural gas and delivers electricity and heat. Furthermore, the customer naturally demands a high level of efficiency and a low level of exhaust fumes and noise emissions, high levels of availability, low capital requirement, and low maintenance costs. The demands with regard to efficiency and emissions are best fulfilled by the fuel cells due to their specific properties. Proof of the availability and maintenance costs must be produced through practical testing of the SOFC which is still in its initial stages. The considerable challenge facing the developers in the medium-term in the reduction of the production costs, so that the fuel cell as CHP comes into direct competition with conventional technology (e.g. gas engines and gas turbine CHPs). The specific investment costs presently stand at 1500–3000 DM kW^{-1} depending on plant size and plant specifications demanded. With that, the target costs for the SOFC have been given.

Today we find ourselves at the stage where the SOFC-technology is, firstly, being tested for demonstration at a larger scale. It is yet to be proven that the high expectations of the public for such technology can be fulfilled. Here, the tubular concept currently has a clear advantage over the planar concept, and one can wait with curiosity to see how the first 100 kW-SOFC-plant proves to be.

The market for fuel cells will goes up mainly in regions with sufficient natural gas supply and natural gas distribution networks, for which it will be assumed that the importance of natural gas will increase world-wide in the next few years. In the medium-term Western Europe, Eastern Europe, North America and Japan in particular, can be named as the main focus.

Since the introduction of SOFC-plants will initially start with unpressurised operating plants, a market for combined heat and electricity generation will appear in the medium-term in the mentioned regions with increasing levels of efficiency (i.e. pressurized operation, in combination with gas turbines), and the introduction of SOFC-technology is very attractive for clean power generation.

The target for the planar concept at Siemens is to put the first 100 kW-plant in operation in 2002/2003. The development and commercial market introduction of bigger pressurized operating systems in the 1 MW-region should be successfully concluded by approximately 2010.

Assuming that the technical problems still exist today are solved, reduction of the present high costs to competitive levels through simpler and new production methods remains a substantial task for the developer. At the end of the day, the purchasing decisions of the customers are influenced superficially by the investment costs, but ultimately by the life cycle costs. Only at a competitive price and additional non-monetary advantages, like the environment, for example, can a market-share be acquired.

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