Present Status and Trends of Fuel Cell Power Generation

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1. Introduction

Fuel cells have been recently reported in the mass media; fuel cell cars were highlighted in the 1999 Tokyo Car Show, and a home-use fuel cell made news. Concern for the environment and energy saving has increased ever since the third conference of parties to the UN convention on climate change (COP3) for environmental preservation held in Kyoto in December 1997, and fuel cells are expected to bring great change in energy supply and use.

At present, except for thermal power plants that require heat in close proximity, mainstream electric energy systems that generate electric energy in large capacity and transmit it over long distances are so-called mono-generation systems, and these systems cannot be said to have high efficiency of energy utilization. In many cases, approximately half of the fuel energy is not utilized and is discharged into the atmosphere or the ocean as waste heat.

As we enter the 21st century, the problem of the environment and energy must be managed not only in Japan but also on a global scale. The fuel cell is a new cogeneration system well suited for environmental preservation, and is positioned as new energy capable of improving the efficiency of energy utilization.

Fuji Electric started to develop fuel cells in the 1960s and has developed fuel cells with various types of electrolytes, including the alkaline type.

This paper describes the present status and trends of the developments, focusing on the phosphoric acid type and solid polymer electrolyte type fuel cells under intense development.

2. Features and Principles of Fuel Cells

2.1 Features

The fuel cell is an electric power generating system that converts the chemical energy of hydrogen, etc. into electric energy using the principle of electrochemical generation. Fuel cells have the following features.

(1) The exhaust is clean and noise is low.

(2) High generating efficiency can be obtained either by a small capacity unit or in a partially loaded condition.

(3) High overall efficiency can be expected by utilizing exhaust heat.

(4) Various fuels can be used.

The fuel cells currently under development are generally classified into four types according to the electrolyte type. The types and features of fuel cells are shown in Table 1.

2.2 Principle of generation

Taking the phosphoric acid type as an example, as shown in Fig. 1, the principle of electric power generation of a fuel cell utilizes the reverse reaction of water electrolysis. Electric power is generated by hydrogen and oxygen fed to the anode (fuel electrode) and cathode (air electrode) arranged on each side of the electrolyte respectively.

The voltage of a fuel cell is highest in a no-load condition and becomes lower with increasing current density of the load. At this time, the part corresponding to a voltage drop is exhausted as heat energy.

<table>
<thead>
<tr>
<th>Type Item</th>
<th>Phosphoric acid type (PAFC)</th>
<th>Molten carbonate type (MCFC)</th>
<th>Solid oxide type (SOFC)</th>
<th>Solid polymer electrolyte type (PEFC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrolyte</td>
<td>Phosphoric acid (H3PO4)</td>
<td>Carbonate (Li2CO3, K2CO3)</td>
<td>Zirconium oxide (ZrO2)</td>
<td>Proton exchange membrane</td>
</tr>
<tr>
<td>Ion conductor</td>
<td>H+</td>
<td>CO32-</td>
<td>O2-</td>
<td>H+</td>
</tr>
<tr>
<td>Fuel (reactant gas)</td>
<td>H2</td>
<td>H2, CO</td>
<td>H2, CO</td>
<td>H2</td>
</tr>
<tr>
<td>Fuel</td>
<td>Natural gas, LPG, methanol, naphtha</td>
<td>Natural gas, LPG, methanol, naphtha, coal gas</td>
<td>Natural gas, LPG, methanol, naphtha, coal gas</td>
<td>Natural gas, LPG, methanol</td>
</tr>
<tr>
<td>Operating temperature (°C)</td>
<td>170 to 210</td>
<td>600 to 700</td>
<td>900 to 1,000</td>
<td>Normal temp. to 100</td>
</tr>
<tr>
<td>Power generation efficiency (%)</td>
<td>35 to 45</td>
<td>45 to 60</td>
<td>50 to 60</td>
<td>45 to 60</td>
</tr>
</tbody>
</table>
Actual working voltage for fuel cells is 0.6 to 0.7V per unit cell. The ratio of heat to electric power at this time is approximately 1:1 and the generating efficiency of a fuel cell stack is 50%. This efficiency of a fuel cell stack is the same irrespective of cell area. Therefore, even a small capacity unit has high conversion efficiency.

To obtain a practical output, many cells are laminated into a fuel cell stack.

2.3 System configuration

When hydrogen is not directly available, the hydrogen fed to a fuel cell stack is made from reformed fuel such as city gas.

The system configuration of a fuel cell power unit is shown in Fig. 2. The reformer is a piece of equipment to convert fuel, such as natural gas, liquefied petroleum gas (LPG) and methanol, into hydrogen-rich gas. The carbon monoxide (CO) produced by reforming is reacted with water in the shift converter to produce hydrogen. The hydrogen produced in this manner and air (oxygen) are fed into the fuel cell stack and generate direct current (DC) power. The inverter converts this DC power into alternating current (AC) power and outputs it. Other additional components consist of the equipment for fuel cell peripheral devices, a cooling device for fuel cell stack, a condenser to recover water generated by reaction, etc.

3. Development Status of Fuel Cells

3.1 Phosphoric acid fuel cells

3.1.1 Overview

Development of the phosphoric acid type is currently most advanced and is near the stage of commercial application. Particularly the on-site type in the 50 to 500kW class is expected to become widespread as a cogeneration system that utilizes heat.

The number of phosphoric acid fuel cells installed by the end of February 1998 reached approximately 420 units including overseas installations, and approximately 190 units of them are still in operation. In Japan, more than 160 units were installed and 81 units are in operation.
Some of these fuel cells demonstrated accumulated operating hours over 40,000 hours, regarded as the targeted useful life of the phosphoric acid type, and further, continuous operation over one year was attained in some cases. Therefore, we judge the reliability to be on a level suitable for practical use.

In Japan, there are three manufacturers of on-site units: Fuji Electric, Toshiba Corp. and Mitsubishi Electric Corp. Toshiba and Mitsubishi Electric are developing 200kW units and Fuji Electric is developing 50kW, 100kW, and 500kW units. Each manufacturer has nearly finished the development of commercial models and is aggressively promoting the introduction thereof into the field through earnest sales activity.

3.1.2 Status of Fuji Electric’s development

Fuji Electric is tackling the commercialization of phosphoric acid fuel cells according to the development plan shown in Fig. 3. Over 90 units mainly of 50kW and 100kW on-site types are in operation, and the accumulated operating time exceeds 1.5 million hours. At six sites, accumulated operating time has exceeded 40,000 hours, which is regarded as a durability criterion. At a certain site, continuous nonstop operation time has exceeded 10,000 hours, which is regarded as a reliability criterion. In particular, operating time has been increasing since the adoption in 1995 of the new model fuel cell developed with experience of the first-generation model as shown in the development plan of Fig. 3. The 100kW commercial prototype and the improved 50kW model supplied in 1997 and the improved 50kW model supplied in 1998 are all operating at a high working ratio over 90%, and this confirms that the performance is on a commercial level.

The commercial type 100kW model FP100E, the cost of which has been reduced to half that of the former model, has been sold from the second half of 1998. The specifications of this 100kW model are shown in Table 2 and the external view is shown in Fig. 4. The shape of this model is a package suitable for outdoor installation. Since the unit is completely assembled at the factory and is transported to the installation site, it therefore has the advantage of quick on-site installation. Giving consideration to the ease of maintenance, it is arranged with large size equipment at the front.

The model has a generation efficiency of 40% (LHV: low heat value) in spite of a small capacity of 100kW, and when exhaust heat is utilized, total efficiency will be greater than 80%. Moreover, as shown in Fig. 5, its advantage is high efficiency not only at a rated-load condition but also at a partial-load condition.

3.2 Solid polymer electrolyte fuel cells

3.2.1 Overview

The solid polymer electrolyte fuel cell (PEFC), which uses a proton exchange membrane as an electrolyte, has recently been receiving attention as an automobile fuel cell. This is due to advantages such as the expectation of high output density, an operating
temperature below 100°C that enables starting from normal temperature, and the wide range from which component materials can be selected which will greatly reduce price through mass production. Because the operating temperature as well as exhaust heat temperature is low, and consequently the heat supply is limited to water heating to 60°C or so, the PEFC under development also targets portable power supplies and comparatively small-scale, distributed power supplies such as for home use.

With regard to portable and distributed power supplies, the New Energy and Industrial Technology Development Technology (NEDO) has commissioned the following companies to develop the following items. Toshiba Corp. is developing a 30kW-class cogeneration power supply using city gas for fuel, Sanyo Electric Co., Ltd. is developing a 2kW-class cogeneration power supply for home use, and Mitsubishi Electric Co., Ltd. is developing a 10kW-class portable power supply that uses methanol for fuel.

In addition, Matsushita Electric Works, Ltd. is developing a portable power supply using butane gas cylinders for fuel and Sanyo Electric Co., Ltd. is developing a 1kW-class portable power supply using hydrogen cylinders. Matsushita Electric Industrial Co., Ltd., Mitsubishi Heavy Industries, Ltd. and Fuji Electric are also actively involved in development.

With regard to automobile power supplies, mainly automobile manufacturers, such as Toyota Motor Corp., Honda Motor Co., Ltd., Nissan Motor Co., Ltd., and Mazda Motor Corp. in Japan and Daimler-Chrysler and Ford abroad, are developing automobiles equipped with a solid polymer electrolyte fuel cell power system. In the 1999 Tokyo Motor Show, Japanese and foreign automobile manufacturers competed against each other in the fuel cell car exhibition. Further, Ballard Power Systems, a Canadian company, not only supplies fuel cell stacks to automobile manufacturers but also is developing a 250kW power supply for bus and stationary use, and Siemens AG. is developing a power supply for submarine and bus use.

### 3.2.2 Status of Fuji Electric’s development

A solid polymer electrolyte fuel cell was installed in the spacecraft “Gemini” and others since the 1960s. At that time, however, it had a defect of insufficient durability of its solid polymer membranes.

As the quality of solid polymer membranes was improved upon since then, Fuji Electric started developing this type of fuel cell in 1989.

Fuji Electric has so far made hydrogen-air type 1 to 5kW units and evaluated the fuel cell stack. In addition, we have promoted the development of element technologies for improving the reliability of fuel cell stacks. The development center, which merged with the phosphoric acid fuel cell department in 1999, is tackling the development of solid polymer electrolyte fuel cell systems using reformed gas from town gas and methanol for fuel.

### 4. The Future and Problems of Fuel Cells

As mentioned above, the fuel cell is a power generating system which is expected to continue to develop in the future because of its excellent environmental properties, energy saving and variety of fuels. In the “General Principles of New Energy Introduction” drawn up by the Cabinet member conference on the comprehensive energy policy in 1994 and the “Long-Term Prospects for Energy Demand and Supply” in 1998, a target was introduced for stationary fuel cells of 2.2 million kW by 2010. Specific governmental measures to introduce fuel cell power systems are the subsidy grant system (subsidized percentage: 1/2 to a municipality or 1/3 to a private corporation) based on the “Special Law for Promoting New Energy Utilization” and the “Taxation System for Promoting Investment to Improve Energy Demand and Supply.”

#### 4.1 Problems of phosphoric acid fuel cells

The manufacturers of on-site phosphoric acid type fuel cells have almost attained the technological level for practical applications and have started making commercial products. These phosphoric acid type fuel cells are expected to lead market development to attain the above-mentioned target. However, like other types of new energy, a comparison of only operational economics cannot provide enough competitive power in the marketplace. To compete with other cogeneration systems, there is a serious problem of cost reduction, and developments to reduce cost are necessary for the future. In particular, the fuel cell stack accounts for 40 to 50% of the cost of the whole generating system, and reduction in the cost of carbon material, the main component material, is considered to be crucial.

In addition to developments to reduce cost, so that fuel cell use becomes more widespread, attempts are made to create applications for fields that effectively utilize the features of fuel cells such as its environmental characteristics and energy savings. There are examples of fuel cell power systems utilizing the unused resource of garbage biogas or a hydrogen by-product. Also, application is being considered to a multi-fuel type fuel cell power system capable of selectively operating on either city gas or fuel stored against emergencies, a high-grade power supply to provide an uninterruptible power supply, and a lifeline base against disaster (life spot).

#### 4.2 Problems of solid polymer electrolyte fuel cells

The problems facing solid polymer electrolyte fuel cells under accelerated development are the completion of the power system, reliability verification by field tests, and cost reduction. With regard to the cost, a scenario can be imagined in which the cost of these fuel cells will be dramatically reduced due to the large scale of the market for automobile use, and the result
will extend to home-use fuel cells. To realize this scenario, by itself, the technical completion of fuel cell power systems for automobile use is insufficient; fuel supply facilities must be completed at the same time. The issue of how to complete fuel supply facilities is also important.

5. Conclusion

Fuel cells that can contribute to the solution of environmental problems and energy resources on a global scale are expected to come into widespread usage beginning in the early part of the 21st century. Further support and technical development are necessary for introducing products in a marketable form. We appreciate understanding and support from the government and individual users.
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