Next-Generation SOFC-Combined Power Generation System (High Efficiency Hybrid Power Generation System)

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An SOFC (Solid Oxide Fuel Cell) is a fuel cell operating at high temperature and can compose a high efficiency power generating system by combining its high-temperature waste heat with a micro gas turbine. Focusing on the potential of SOFC as a high efficiency power generation system, Mitsubishi Heavy Industries, Ltd. (MHI) has promoted development from both element and system aspects so far. And at present, field verification tests of the 250kW-class SOFC-MGT hybrid demonstration system brought by successfully combining the tubular type SOFC with a micro gas turbine (MGT) in the studies commissioned by the New Energy and Industrial Technology Development Organization (NEDO) are under way at Tokyo Gas Co., Ltd.'s Senju Techno Station.

1. Introduction

So that the reduction of CO_2 emissions in order to limit global warming be made compatible with the stable supply of electric power that is indispensable for the modern society, it is necessary to rationally, through the best mix in both qualitative and quantitative terms, combine the advanced electric power network built on centralized power supply sources including thermal power generation with high efficiency decentralized power sources and new energy including renewable one. And, partly for the global preservation of energy resources, it is indispensably and urgently required to use fossil fuel as effectively as possible by developing and quickly diffusing a high efficiency power generating system.

2. Development of SOFC in details

MHI has so far proceeded with the development of a combined power generation system where SOFC, a fuel cell operating at high temperature, is put together with another power generation system and is now at the stage of demonstration for commercial application of a hybrid system.

As shown in **Figure 1**, the hybrid system incorporates SOFC in the upstream of the micro gas turbine. Since this SOFC is installed in the high pressure area upstream from the micro gas turbine combustor and operates at as high as 900ºC, all-ceramic robust-structure tubular type SOFC was developed and adopted. If waste heat recovery equipment is installed on the exhaust gas line, then it can bring a co-generation system which supplies steam and hot water at the same time.

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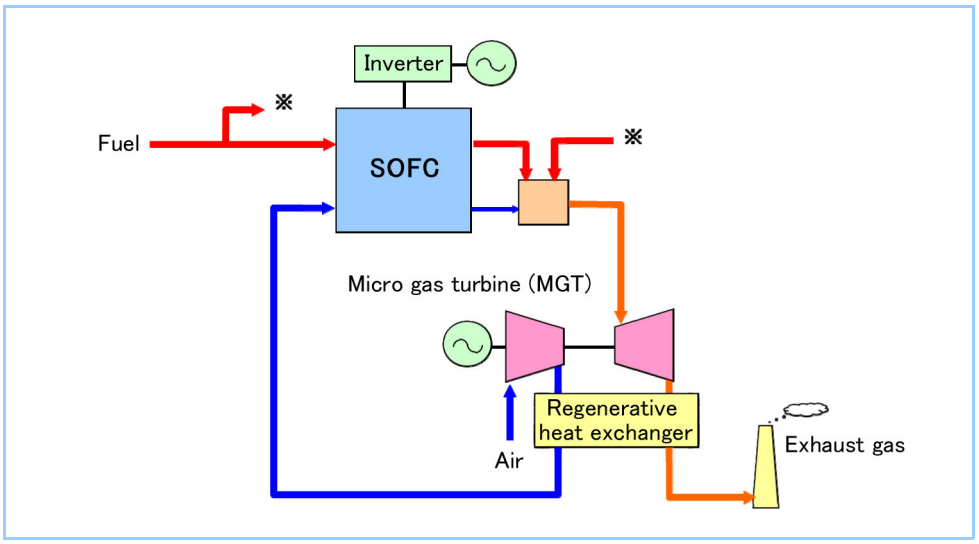


Figure 1 Hybrid system

3. Recent state of development

3.1 Composition of tubular type SOFC

Figure 2 illustrates the structure of a cell stack, the power generation element of tubular type SOFC. On the outer surface of the substrate tube, a structural member made of high-strength ceramic, a device (laminated anode, electrolyte, and cathode) reacting to generate power is formed and an electron-conductive ceramic interconnector connects these devices in series. This permits low-current high-voltage electricity to be efficiently taken out from each cell stack.

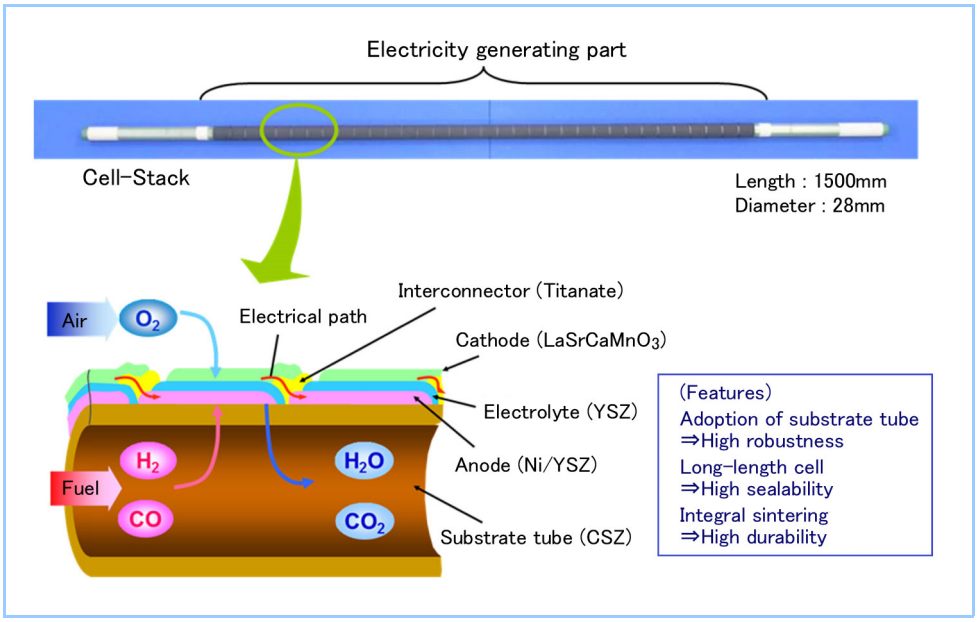


Figure 2 Structure of cell-stack

These cell stacks are bundled to output electricity of 15kW- 33kW and are provided with the functions of a bearing member, fuel and air supply/discharge and electric current discharge to compose a cartridge. A set of cartridges with the necessary capacity, which are collectively contained in a pressure vessel, constitutes a module. The adoption of such a layered structure aims at systematization by taking installation, and even maintainability, into consideration. This pressurized SOFC module was combined with a gas turbine, thereby realizing an SOFC combined cycle system (**Figure 3**).

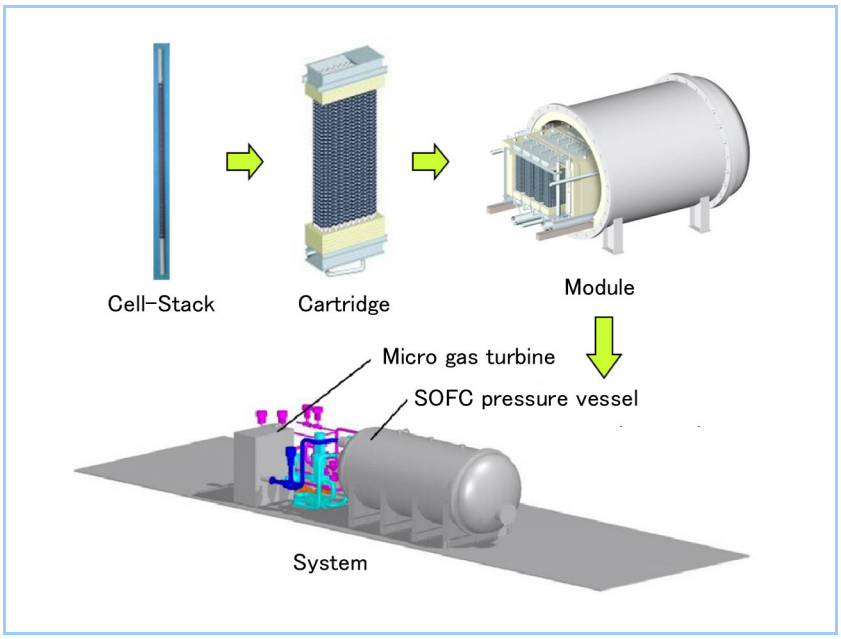


Figure 3 Structure of module system

3.2 Development of tubular type SOFC

From fiscal 2008, under the NEDO development project, we were engaged in the improvement of the reliability of the cell stack, module and combined cycle system, respectively, as well as in the development of system operation control technology.

Concerning the cell stack, the analytical and examination results from the "Durability/Reliability Improvement" project that analyzed/examined our tubular type cell stack's changes over time were reflected in higher durability. This limited the cation transfer in the cathode interlayer, which was thought to be the main cause of such changes over time. This cell stack was subjected to a normal-pressure, 7000-hour or longer continuous power generation test, proving epoch-making durability with no voltage drop over time (zero cell voltage decay rate against the NEDO's target of 0.25%/1,000 hours or less) (**Figure 4**).

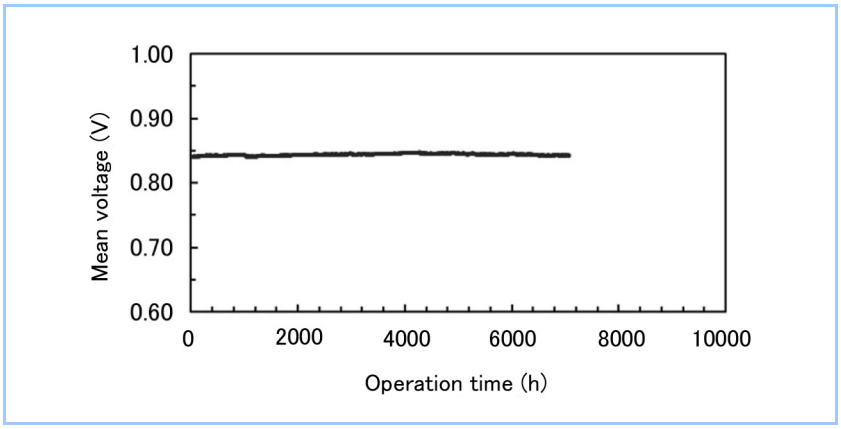


Figure 4 Cell-Stack test for continuous operation

We have also been developing our own high performance cell stack. Compared with the 48 cells of the conventional cell stack called Model 06, Model 10 raised the number of cells to 85. At the same time, the power output per cell stacks has been enhanced by 30% such as by optimizing the interconnector composition and adjusting the cathode interlayer. We are now struggling to further improve the efficiency and, in the Model 15 cell stack, measures were taken, including cathode-electrolyte interlayer as well as cathode-interconnector interlayer optimization and electrolyte film/substrate tube thickness thinning, finding the output density improved by 50% from Model 10's (**Figure 5**).

In addition, an Model-10 cartridge with the cell stack packing density doubled from Model 06's was developed and commercialized for its higher per-unit volume output density. The higher

packing density is accompanied by a higher heating density, but the heat transfer/cooling design of cartridges has got heat transfer characteristics under control, ensuring the conventional level of heat transfer in the power generating area as well as in the heat exchange area across the power generation area. And, in Model-15 cartridges, their narrower diameter and longer length are intended to increase the power output per unit volume further substantially.

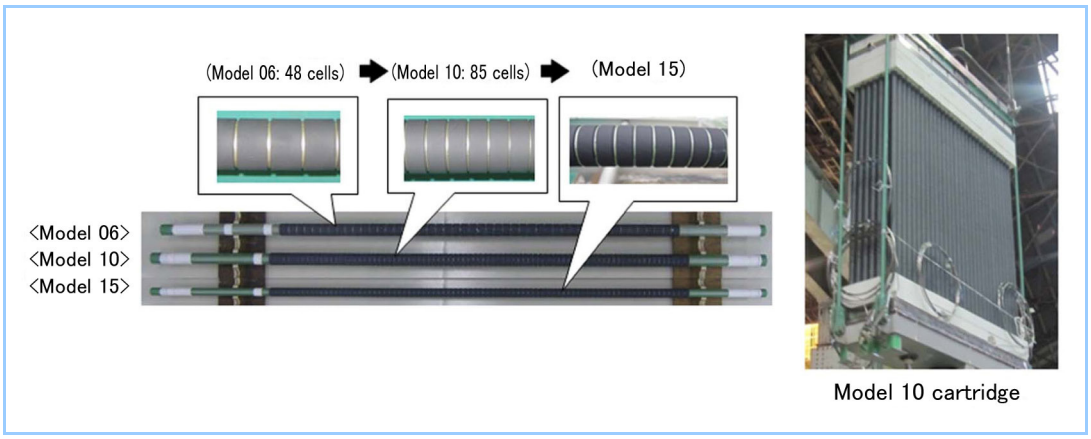


Figure 5 Development of high performance cell-stack and packing density improvement of cartridge

3.3 SOFC-MGT hybrid demonstration system

Based on achievements thus far, from fiscal 2011 to fiscal 2012, under the NEDO project, we were engaged in the development of a 250kW-class SOFC-MGT hybrid demonstration system. After requirements for SOFC/MGT protection were met, the system composition/arrangement was examined for the simplification of the combined cycle power generation system as a whole. For the MGT, combustor development/adaptation based on a commercial MGT made by Toyota Turbine and Systems Inc. was followed by tests for tubular type SOFC-linked operation, where starting, state operation, emergency stop, and other functions were operated, finding no problems, and it was safely adopted into the hybrid demonstration system.

This demonstration system adopts the above-mentioned Model-10 cartridge in an attempt to make its SOFC module more compact. It has become possible not only to substantially shorten the SOFC module length but also halve its installation area from such a length and an area for previous pilot systems adopting the Model-06 cartridge. Future commercial systems are intended to be made even more compact through the adoption of the Model-15 cartridge (**Figure 6**).

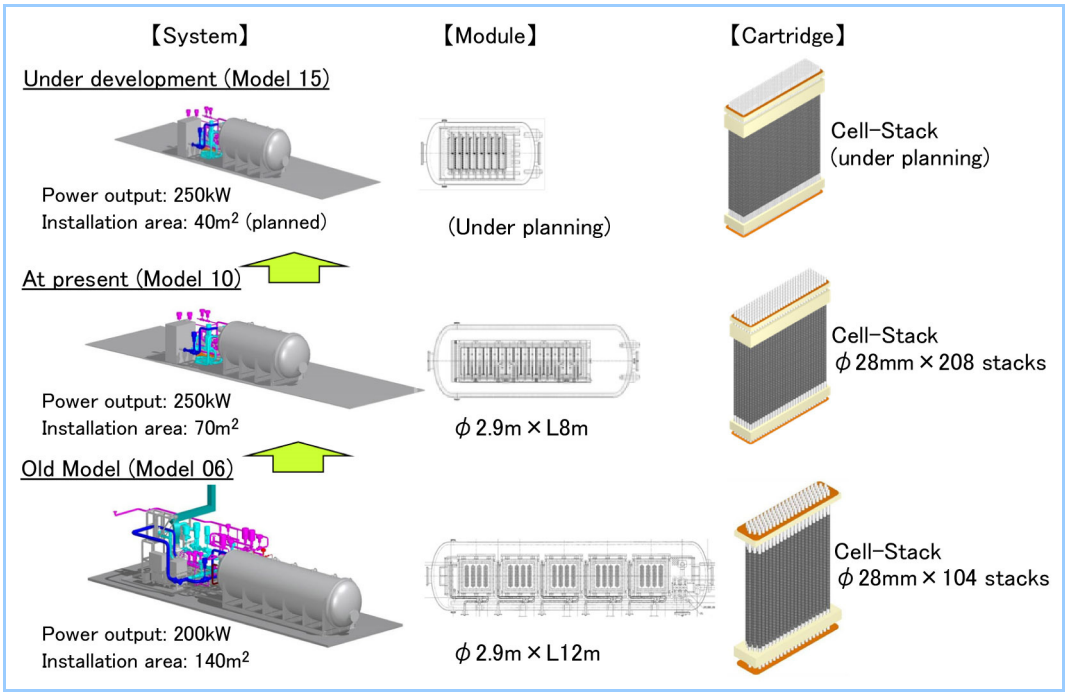
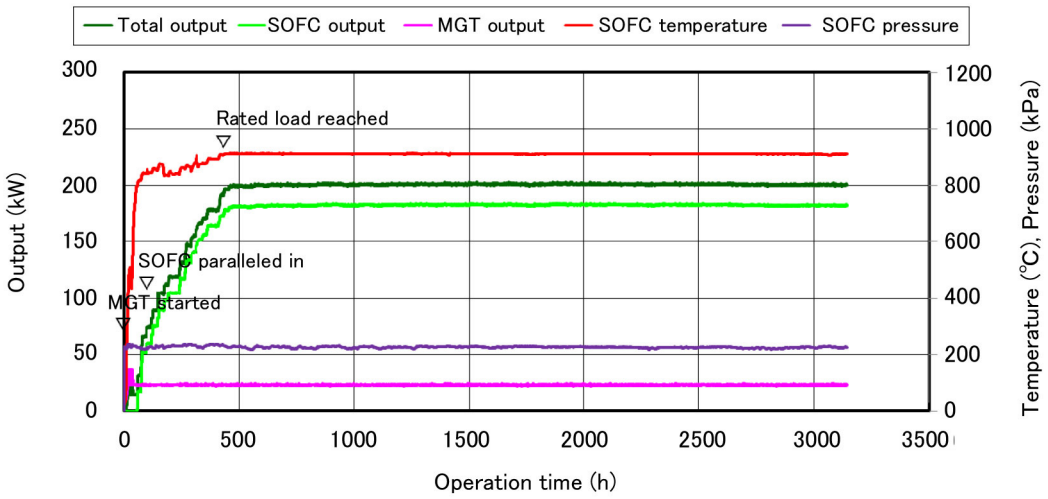


Figure 6 Development of cartridge, module and system

Field tests of SOFC-MGT hybrid demonstration system are under way at Tokyo Gas Co., Ltd.'s Senju Techno Station and demonstrative operation is still continued in fiscal 2013 as part of NEDO-subsidized project for likely achievement of world-unprecedented over 4,000-hour continual operation at least by September in which the program is halted (**Figure 7**). Under such circumstances, we plan to verify long-term system stability as well as extract problems that need to be considered in order to expedite introduction. At present in particular, because the SOFC-MGT hybrid system is rated as a power generation system that has to be monitored at all times, we are targeting the necessary reconsideration of the regulatory requirements for continuous monitoring so that the system would be diffused in earnest. We, therefore, intend to examine/verify the system's reliability, as well as its safety, and continually acquire data that will contribute to deregulation.



・Remains in continual rated-load operation since being started on March 15
・As of 18:00 on July 24, a continuous power generation time of 3,098 hours and an accumulated operation time of 3,382 hours have been reached.
(Because it was demonstration system, load was increased in sufficient time as planned.)

Figure 7 System long-term Durability demonstration system

4. Toward commercial application of SOFC

Regarding a hundreds of kilowatt- to MW-class high efficiency hybrid power generating system for decentralized power sources, our desire is to, by taking advantage of its high power generation efficiency, quietness, environmental feasibility, and other outstanding characteristics as co-generation equipment for business purposes and industrial applications, provide such a system to the general market in 2015 at the latest for our customer's evaluation following the field verification tests at Tokyo Gas Co., Ltd.'s Senju Techno Station.

5. Conclusion

At present, when the development of effective technology to make the reduction of CO_2 emissions more compatible with the stable supply of electricity is urgently required, significant hope is being placed on the early commercialization of ultra-high efficiency power generation systems using fossil fuel. Rating the hybrid system as the trump card for CO_2 reduction in the co-generation market, we would like to steadily establish the technology, and at the same time, expedite its commercial application, thus greatly contributing to the development of "a safe and sustainable energy/environmental society for the 21st century."