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Power generation efficiency of an SOFC–PEFC combined system with time shift utilization of SOFC exhaust heat

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ABSTRACT

A microgrid, with little environmental impact, is developed by introducing a combined SOFC (solid oxide fuel cell) and PEFC (proton exchange membrane fuel cell) system. Although the SOFC requires a higher operation temperature compared to the PEFC, the power generation efficiency of the SOFC is higher. However, if high temperature exhaust heat may be used effectively, a system with higher total power generation efficiency can be built. Therefore, this paper investigates the operation of a SOFC–PEFC combined system, with time shift operation of reformed gas, into a microgrid with 30 houses in Sapporo, Japan. The SOFC is designed to correspond to base load operation, and the exhaust heat of the SOFC is used for production of reformed gas. This reformed gas is used for the production of electricity for the PEFC, corresponding to fluctuation load of the next day. Accordingly, the reformed gas is used with a time shift operation. In this paper, the relation between operation method, power generation efficiency, and amount of heat storage of the SOFC–PEFC combined system to the difference in power load pattern was investigated. The average power generation efficiency of the system can be maintained at nearly 48% on a representative day in February (winter season) and August (summer season).

1. Introduction

PEFC (proton exchange membrane fuel cell) and SOFC (solid oxide type fuel cell) have been developed as fuel cells for houses [1–3]. The SOFC requires a higher operation temperature compared to the PEFC. However, the power generation efficiency is higher in SOFCs, and high temperature exhaust heat can be widely used. The SOFC–GT (gas turbine) combined system was developed as an effective method to use the high temperature exhaust heat of SOFC [4–8]. In this combined system, the exhaust heat of the SOFC is used as a heat source in the heat transfer medium of the GT. Generally, calculations for the efficiency of an energy system require knowledge about the load pattern. Operation of the GT is dependent on the amount of exhaust heat of the SOFC. Furthermore, the exhaust heat of the SOFC and operation of the GT synchronize. Therefore, the load following operation of a microgrid using the SOFC–GT combined system cannot maintain high thermal efficiency. In the combined system with the load following operation of the GT, and base load operation of the SOFC, since the partial-load characteristic of the GT is poor, the power generation efficiency of the whole system is not high. In the combined system with the base load operation of the GT and load following operation of the SOFC, since the exhaust heat of the SOFC is not stabilized, the production of electricity of the GT is restricted. Moreover, the power generation efficiency during partial-load of the SOFC is greatly reduced compared to full-load operation. Consequently, in order to obtain high power generation efficiency with the SOFC–GT combined system, either storage-of-electricity

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equipment needs to be installed or uniform system load is required. Therefore, this paper examines a system which produces reformed gas with high hydrogen concentration using the exhaust heat of the SOFC. The system is characterized by the ability to shift the utilization time of the produced reformed gas. Flexible operation can be planned because it is not necessary to synchronize the exhaust heat output of the SOFC and utilization of the reformed gas. In this paper, the installation of a SOFC–PEFC combined system into a microgrid used for supplying energy to 30 houses in Sapporo, Japan is assumed. The SOFC is made to correspond to the base load operation of the microgrid, and the PEFC is made to correspond to the fluctuation load in the proposal system. In this case, reformed gas is produced by supplying the exhaust heat of the SOFC to a steam reformer using natural gas. This reformed gas is stored, and the system operation method for the next day is planned with reference to the amount of stored reformed gas. In this study, fuel consumption of all equipment, power generation efficiency, and operation method of heat storage and boiler, when operating the SOFC–PEFC combined system under different load patterns, is investigated. From this result, the load characteristics of the system and average power generation efficiency when installing the proposed system into the microgrid are elucidated.

2. System scheme

2.1. *Microgrid model*

Fig. 1 shows a power system model of a microgrid with 30 houses. This microgrid is installed into a residential area; power and heat are supplied by introducing a SOFC–PEFC combined system. The SOFC outputs high temperature exhaust heat at 750–900 °C. In this study, a steam reformer of natural gas is operated using this high temperature exhaust heat. The reformed gas is stored in a cylinder, and the stored gas can be supplied to the PEFC at an arbitrary time. Flexible operation can be planned because the exhaust heat of the SOFC and power generation of the PEFC is not synchronized. On the other hand, load with various fluctuations added to the microgrid is expected. Accordingly, this study investigates operation of the SOFC–PEFC combined system using three different power load patterns.

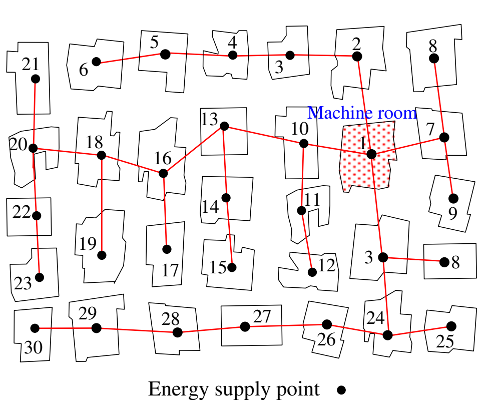


Fig. 1 – Microgrid model of a power system.

2.2. *SOFC–PEFC combined system*

2.2.1. *Power system*

Fig. 2 is the block diagram of the SOFC–PEFC combined system examined in this paper. The SOFC installed into the system assumes an internal reforming type. Natural gas and air for supplying the SOFC are heated by the SOFC exhaust through a heat exchanger (HEX). The exhaust heat of the SOFC is supplied to a steam reformer (R/M) of natural gas, and reformed gas with high hydrogen concentration is produced. Water contained in the reformed gas is removed with an air-cooling condenser (C/S). After reducing the carbon monoxide in the reformed gas to several ppm by using CO oxidation equipment (C/O), the reformed gas is stored in a cylinder. The reformed gas stored in the cylinder can be supplied to the PEFC at a later time. The power of the SOFC and PEFC is supplied to DC–DC and DC–AC converters. Finally, after changing this power to the target voltage and frequency through an inverter, the power is supplied to the microgrid.

2.2.2. *Heat system*

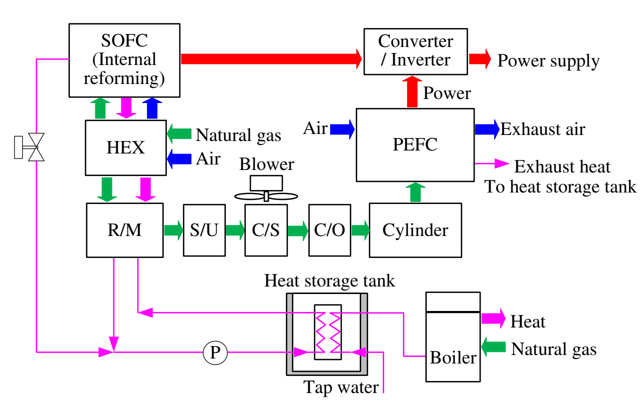
First, the exhaust heat of the SOFC is used for heating natural gas and air. The remaining exhaust heat is supplied to the steam reformer (R/M) of natural gas. The exhaust heat of the natural gas steam reformer is stored in a heat storage tank. A heat exchanger is installed in the heat storage tank, and heat is exchanged between tap water and heat medium. A boiler is operated when the temperature of the heated tap water does not meet demand.

2.3. *Operation method of the system*

Fig. 3 shows the power operation model of the SOFC–PEFC combined system introduced into the microgrid.

2.3.1. *Model A*

In Model A, shown in Fig. 3a, Fuel cell A corresponds to base load operation of the microgrid, and Fuel cell B corresponds to fluctuation load. Here, the base load of Model A is setup smaller than the minimum of the load fluctuation. In this case, Fuel cell A is operated at maximum power generation efficiency at all times.



C/O : CO oxidation unit, C/S : Condenser unit, HEX : Heat exchanger,
R/M : Reformer, S/U : Shift unit

Fig. 2 – SOFC–PEFC combined power system.