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Operational analysis of a small-capacity cogeneration system with a gas hydrate battery

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ABSTRACT

In a cold region during winter, energy demand for residential heating is high and energy saving, the discharge of greenhouse gases, and air pollution are all of significant concern. We investigated the fundamental characteristics of an energy storage system with a GHB (gas hydrate battery) in which heat cycle by a unique change in state of gas hydrate operates using the low-temperature ambient air of a cold region. The proposed system with the GHB can respond to a high heat to power ratio caused by a small-scale CGS (cogeneration system) that is powered by a gas engine, a polymer electrolyte fuel cell, or a solid oxide fuel cell. In this paper, we explain how the relation between fossil fuel consumption and heat to power ratio of the different types of systems differ. We investigated the proposed system by laboratory experiments and analysis of the characteristics of power load and heat load of such a system in operation in Kitami, a cold district in Japan. If a hydrate formation space of 2 m^3 is introduced into the proposed system, 48%–52% (namely, power rate by green energy) of total electric power consumption is supplied by the GHB.

1. Introduction

In Japan, systems for residential space heating commonly used at the present time include heating by a kerosene stove, a kerosene boiler, an air source heat pump, a geothermal heat pump, an electric storage heater, or an electric water heater [1–3]. Natural gas is now widely available in urban areas, however, and its use for space heating and home electricity production is expected to expand in the future [4–6]. In winter, energy demand for heating is high and energy saving, greenhouse gas emissions, and air pollution are serious concerns [7–9]. Therefore, the need for clean energy systems that can respond to the demand with a high heat to power ratio is apparent. Introduction of small-scale CGSs (cogeneration systems) suitable for an individual dwelling is progressing in Japan, and use of small systems powered by a gas engine, a PEFC (polymer electrolyte fuel cell), or a SOFC (solid oxide fuel cell) has spread [10–13]. However, because the different types of standard CGS described above provide only 30%–40% of the electricity demand, they are always interconnected with a commercial power system. When an interconnected CGS is introduced, it is necessary to pay fee of commercial electric power, and fuel charge of the CGS. Considering the entire electric power system, the improvement in economic efficiency and decrease in environmental impact by the introduction of small-scale CGSs for residences has, up to this point, been limited. Moreover, operation of a basic CGS during winter does not indicate that no additional space heating is required, because the heat demand cannot be filled only with exhaust heat of the small-scale CGS. Therefore, another high capacity heat source is required. Heat supplied by a boiler raises environmental issues and when an electric heat pump is introduced into the system, a CGS with twice the conventional capacity is required. Therefore, in this paper, the heat transfer characteristics of gas hydrate generation and dissociation characteristics by plate heat exchangers, and a miniaturization of a gas hydrate tank by increase in the generation rate of gas hydrate using a catalyst are newly investigated by analysis and experiment.

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In this study, we propose a new distributed energy system with a GHB (gas hydrate battery). In the GHB, heat cycle by a unique change in state of gas hydrate is employed, which is driven by a temperature gradient between the outside temperature of a cold region and geothermal heat. The unique change in state of a gas hydrate is as a result of the phase equilibrium state of formation and dissociation of the gas hydrate, which produces large differential pressures in response to small temperature changes. For example, when CO_2 hydrate changes from 0 °C to 10 °C, the phase equilibrium curve of formation and dissociation shows that the difference in pressures is approximately 3 MPa. Thus, if the pressure of the dissociation (that is, the expansion of the gas hydrate) is transferred to an actuator, a large power transfer can be realized by a small difference in temperature. Because gas hydrate is easy to store, its heat cycle can be used as accumulation-of-electricity equipment by combining it with an actuator, thus forming a GHB.

In this paper, we propose a small-scale hybrid CGS and GHB system to provide for all the electricity and heat requirements for an individual house in a cold region; the proposed system is not connected to a commercial power system. Furthermore, we evaluate the equipment required and assess the capacity of the system. When the ambient winter air (low-temperature side) and geothermal heat (high-temperature side) are used as heat sources for the GHB, the energy supplied by the GHB increases with increasing rate of green energy supplied to individual houses. However, because of the output characteristics of electric power and the heat change with different types of power for the small-scale CGS (a gas engine, a PEFC, or an SOFC), it is necessary to clarify the relation between each power source, and the operational methods and equipment capacity. The objective of this paper is to clarify how the installation of a hybrid distributed energy system in a house would affect fossil fuel consumption. The hybrid energy system consists of a small-scale CGS powered by a gas engine, a PEFC, or an SOFC paired with a GHB. We consider both the method of operation of the system and the relation between the heat to power ratio and fossil fuel consumption. Furthermore, we propose a new distributed energy system based on the results of the investigation described above that would contribute to solving

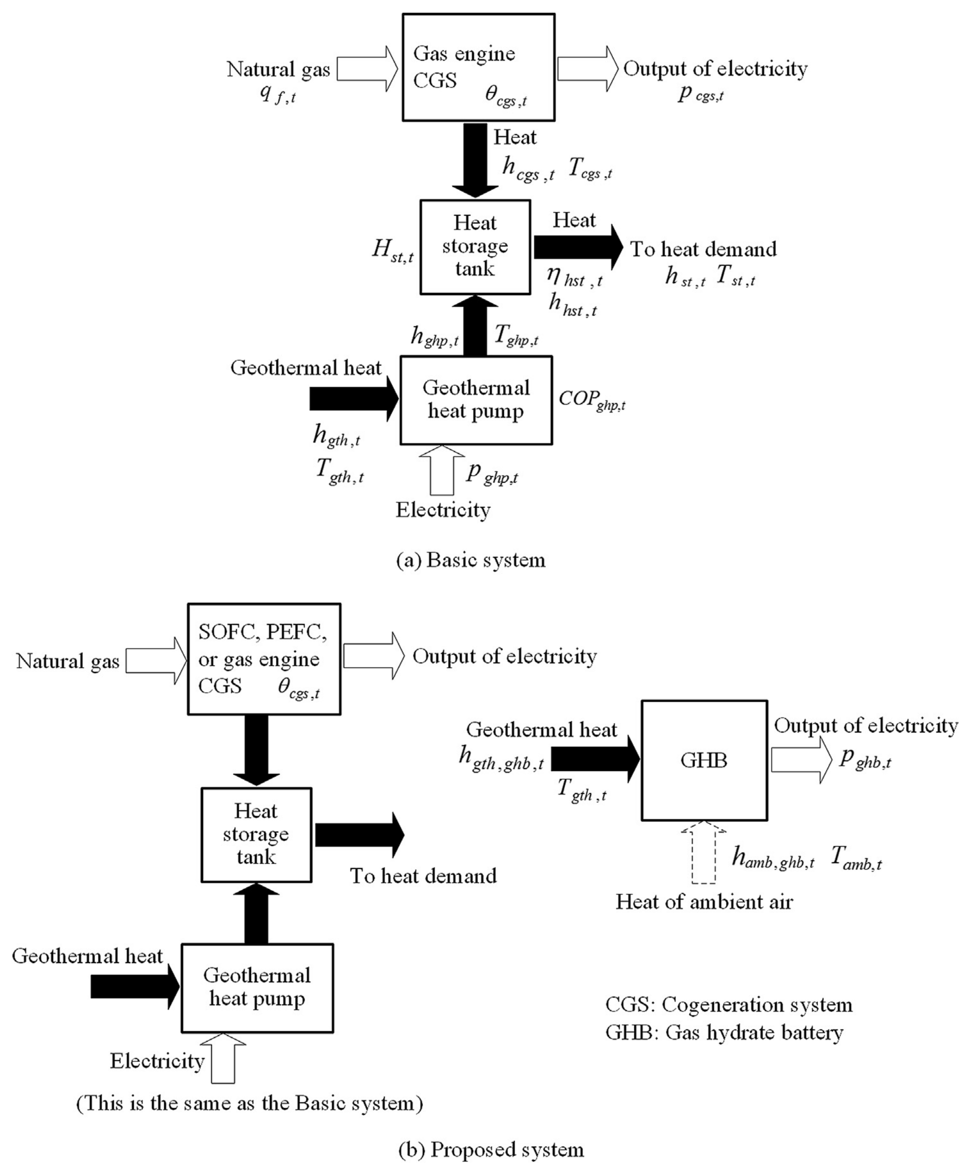

Fig. 1. Schematic diagrams showing energy flow in the analyzed systems.