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Micro gas turbine cogeneration system with latent heat storage at the University: Part I: Plan and energy flow test

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HIGHLIGHTS

- Proper use of latent heat storage system saves energy and reduces exhaust emissions.
- Cogeneration with latent heat storage was demonstrated under service conditions.
- Total 407 charge/discharge cycles of the latent heat storage were repeated.
- Energy flow test shows the importance of heat release source and total system design.

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ABSTRACT

Overcoming the spatiotemporal mismatch between heat and electricity utilization is a major issue in distributed energy systems. Latent heat storage systems are able to store heat for a long period of time with little heat loss. The Energy Technology Research Institute (ETRI) of the National Institute of Advanced Industrial Science and Technology (AIST) demonstrated a micro gas turbine cogeneration system with latent heat storage at Sapporo City University. Since there had been no cogeneration system with the latent heat storage under service condition, this system was the first demonstration and its characteristic was very important. The proper use of the latent heat storage system will save energy economically, store high energy density, reduce exhaust emissions, and save operational costs.

The latent heat storage system operated well and was able to repeat 407 cycles of heat storage and heat release. The efficiency of the electricity generation was about 20%, although the efficiency of the total system remained at 55%, which was lower than the nominal specifications. Heat loss, which amounted to 45%, was from a decrease in the efficiency of the heat exchanger, piping loss around the heat exchanger, heat loss due to cooling of auxiliary equipment, and heat loss due to exhaust gas out of the building. Heat loss of the heat exchanger system and piping loss can be diminished by making better use of the highly sophisticated system. The proper solution is to operate the system for more than 4 h until sufficient heat is stored in the latent heat storage system. This would decrease the heat loss from both the heat exchanger system and the piping.

In Part II [1], an irregular charge case of the latent heat storage system was discussed when the prime mover of the system was operated at a part load and thermal priority mode. A highly sophisticated system design that solves these problems was necessary for extending the latent heat storage system.

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In Part III [2], a temperature control schedule of the system was demonstrated in winter morning using a new programmable logic controller (PLC). If the more larger latent heat storage system will be developed in the future, it will be expected greatly that the temperature of the classrooms are kept more comfortable with less energy consumptions and less CO_2 emission.

1. Introduction

A cogeneration system efficiently supplies electric power and heat in a distributed energy system. Cogeneration systems were initially used mostly to compensate for an imperfect supply of grid power [3,4]. More recently, they have widely been used to help prevent global climate change and reduce energy costs. The prime movers utilized in such systems are gas turbines [3–6], gas engines [7,8], Stirling engines [9–11], and fuel cells [12]. The gas turbine is a good choice for larger distributed energy systems. Compared to reciprocating engines, gas turbines have higher specific power, are easy to soundproof and contain relatively few working parts [5]. Micro gas turbine cogeneration systems have become widespread over the past decade [13,14]. Among such systems, the Capstone C30 (30 kW) and C60 (60 kW) [13] are well known for their recuperation cycle and high electrical efficiency. Many studies have analyzed the energy [15,16], exergy [3] and economy [17,18] of micro gas turbine cogeneration systems. However, these analyses were based on rated, nominal load specifications. Such limited field tests may obscure the actual efficiency and performance of such systems [5].

The National Institute of Advanced Industrial Science and Technology (AIST) is a public research institution funded by the Japanese government and has been contributing to society through continuous advancement in technologies and support to Japanese industries. From 2006 to 2010, the Energy Technology Research Institute (ETRI) of AIST demonstrated micro gas turbine cogeneration system with latent heat storage at the University. The latent heat storage system was an original design of AIST [19], and it used phase-change material (PCM) [20]. Latent heat storage systems are able to store heat for a long period of time with little heat loss. They utilize waste heat due to spatial and temporal mismatching when there is a difference between the time that electric power is generated and the time that heat is utilized. Overcoming this spatiotemporal mismatch in heat use and electricity utilization is the major challenge in distributed energy systems.

The latent heat storage system was a novel heat storage system, and it was demonstrated with a micro gas turbine cogeneration system at the University under service conditions. Expanding the latent heat storage system is greatly expected to save energy and initial and operational costs, and to reduce exhaust emissions. It is necessary to perform proper operation in the higher power cogeneration system with latent heat storage. Since there had been no cogeneration system with latent heat storage under service condition, this system was the first demonstration and its characteristic was very important. Proper use of the latent heat storage system will save not only energy but also initial and operational costs. In addition, the new storage system reduces exhaust emissions.

In Part I, the plan and energy flow test of the system was described. An operation schedule of the cogeneration system with latent heat storage was planned, and then the system was demonstrated at the University under service conditions. The latent heat storage system was charged during the daytime and discharged during the evening and next morning. Total 407 charge/discharge cycles of the latent heat storage system were repeated at the University. The latent heat storage system saved energy, but the total system efficiency was not so high. The energy flow test of the cogeneration system revealed the importance of the heat exchanger and operational time for heat storage.

In Part II [1], a part load and thermal priority mode of the cogeneration system was described. An irregular charge case of the latent heat storage system was discussed. In normal situation, the latent heat storage system was expected to save energy and reduce exhaust emissions. Surplus heat of the cogeneration system made a gas turbine operated at a part load and thermal priority mode. In the specific system, when controlled to heat quantity of heat exchanger of the cogeneration system, the latent heat storage system failed because of low charging temperature of PCM. When maintaining high charging temperature of PCM, mechanical damage might occur to the gas turbine because of the switchable combustor design. These problems were not solved in the specific system, but will be solved in the highly sophisticated designed system with the latent heat storage.

In Part III [2], a temperature control schedule of the system was described. Apart from a fixed operating schedule, temperature control schedule in winter morning was demonstrated at the University because it was expected to save energy, CO_2 emissions, and operational costs. The charge/discharge sequences of the latent heat storage system were interlocked with the operation of the micro gas turbine, and it was repeated completely using a new programmable logic controller (PLC). Temperature rise of the big lecture hall was controlled, and it was proportional to heat supply to header system of the building. Temperature rise will be improved if controlling start time of air-heater and heat output of the original boiler. A highly sophisticated system design that the more larger latent heat storage system heats the big lecture hall in winter morning will be expected to drastically improve the temperature of the classrooms being kept more comfortable with less energy consumptions and less CO_2 emission.

2. Joint research with the University

Sapporo City University (http://www.scu.ac.jp/) was established in April 2006 and is located in the suburbs of Sapporo city, where there is more snowfall than in the center of the city. The former body of the Sapporo City University was the Sapporo School of the Arts established in April 1991. It included a main building, Building A, Building B, a gymnasium, a library, and other buildings on campus. Building C was newly built in 2006, which coincided with the official opening of the University. This building had 3 floors above ground and 1 in the basement, with 13 classrooms, 1 big lecture hall, 2 shower rooms, 1 locker room, and 6 lavatories. The total floor area was 4163 m^2.

The ETRI of the AIST is aware that distributed energy network systems are key energy technologies for attaining a sustainable society where limited fossil resources must be utilized efficiently to suppress global warming. Cogeneration systems have been proposed as useful technologies for distributed energy network systems. The ETRI entered into a memorandum of understanding (MoU) with the office of Sapporo city in December 2004, and demonstrated a cogeneration system with latent heat storage at the University from 2006 to 2010. During the design of the system, various types of prime movers were considered to identify which