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Electricity supply characteristics of a biogas power generation system adjacent to a livestock barn

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ABSTRACT

In order to consider the potential for electricity supply from a biogas power generation system (BGP) located adjacent to a livestock barn, the power balance was determined by using both simulation and actual measurement. Examination of power balances at the barn and the BGP showed that a certain amount of electricity for supply could be secured based on load leveling in both tie-stall barns and free-stall barns. BGPs are a viable renewable energy (RE) power source that can produce enough electricity for system operation and maintenance as well as a significant surplus of supply for power companies and other users. BGPs have the potential to allow output control appropriate for the relevant amount of gas storage. Further, output control based on the use of a gas holder in combination with changes in the number of biogas generators could allow more efficient usage of biogas. Specifically, the range of power output adjustment can be widened through parallel operation of several biogas generators, instead of a single generator. In other words, one biogas generator uses a constant power supply, and the other uses it to control the output for the related amount of gas storage. In this way, the possibility of achieving a constant electricity output through biogas power generation system and a regulated power supply was demonstrated.

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1. Introduction

Since the enforcement of the feed-in tariff (FIT) scheme for renewable energy (RE) power sources in 2012, the amount of solar photovoltaic and other RE power sources connected to power grid has been rapidly increasing. RE power sources had conventionally drawn attention because of their favorable characteristics, including their status as independent distributed sources of power that are resistant to disasters. Particularly, since the March 2011 Great East Japan Earthquake, which caused considerable damage to power supply facilities in Japan, there have been even higher expectations for RE as a power source that can both help to reduce greenhouse gas emissions as well as provide energy security.

Meanwhile, it should be kept in mind that RE is an unstable power source, whose capacity is significantly influenced by weather conditions. Accordingly, increasing connection of RE power sources to the grid is expected to hinder the achievement of supply-demand balance and possibly undermine grid stability. As a result, it is necessary to consider limiting the amount of electricity from RE sources that connect to the grid in the region. To solve these problems, efforts to verify the feasibility of using storage battery technology are under way for the stabilization of RE output. However, stabilization of the grid using such batteries involves significant initial investment, which may hinder the widespread use of RE power sources.

For the purpose of assessing the characteristics of electricity supply by biogas generation systems (BGPs), the authors focused on cases at the barn with particular emphasis on the controllability characteristics of 1) BGP support for the storage of electricity in gaseous form and 2) the stability of feedstock supply and the

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absence of any adverse effects caused by weather conditions on amounts of power generated.

The results of related assessment are expected to serve as a benchmark for the introduction of RE power sources in Hokkaido prefecture and throughout Japan in the coming years. If grid interconnection requirements for the RE power sources or the commercial approaches of power producers change in the future, BGPs can probably serve as small locally distributed power plants because the generated electricity can be either consumed on-site or sold, thereby supporting their broader introduction along with other RE power sources.

In this study, the power balance for the barn with BGP was verified using simulation and actual measurement to assess the potential for electricity supply from the plant. In addition, the method for controlling the power-supply rate from BGPs to other power consumers was examined.

2. Materials and methods

2.1. Objective farms

A total of 48 BGPs are located in Hokkaido prefecture, Japan where agriculture is a major industry (Matsuda and Ishikawa, 2010), particularly, on medium-scale farms with approximately 200 parous cows. This study addressed two medium-scale farms (referred to here as Farm A and Farm B; Table 1).

Farm A comprised typical free-stall barns and Farm B comprised tie-stall barns. Because neither farm had unique equipment among their facilities, it was considered appropriate to simulate power balance by applying the BGP method on these farms. As shown in Table 2, the BGP used for actual measurement was surveyed (Farm C).

The BGP method used for both the simulation and the measurement was mesophilic fermentation. These BGPs were selected from medium-scale farms (the most common type in Hokkaido prefecture). At these BGPs, a combined daily total of manure from 200 to 250 parous cows and milking parlor wastewater was treated. The biogas generated in these BGPs was used to fuel a 40-kW to 75-kW biogas generator. For both simulation and actual measurement, the selected BGPs maintained stable operation throughout the year in terms of a stable supply of feedstock, internal fermenter temperature, and utilization of biogas.

2.2. Methods of investigation

In the simulation, data on major BGP equipment (Table 3) was applied to Farms A and B without BGP. The power balance for the barn and the BGP methods were then examined. Under normal conditions, it was assumed that the introduction of a BGP would require retrofitting of existing facilities or new capital investment. However, the simulation was performed assuming that major equipment was not changed. The authors interviewed manufacturers regarding the operational period of each type of equipment, and clarified standard operational patterns and conditions such as timer use.

Because power consumption was measured on a monthly basis, it was difficult to assess daily use and temporal fluctuations for each type of dairy farming equipment. Accordingly, the power consumption of major BGP equipment (Table 4) on Farm C was measured using data loggers connected to power distribution boards. A Clamp On Power HiTester 3168 (Hioki E. E. Corporation, Japan) was used for this purpose. Power lines from three-phase (200 V) and single-phase (100 V) power distribution boards were attached to measure voltage (V), current (A), and active power (kW) at 1-min intervals for 24 h. Using a multimeter in biogas generator was calculated based on the voltage and current. The data pertaining to power output of the biogas generator were recorded by the loggers at 3-s intervals.

2.3. Items for investigation

BGP facilities consist primarily of the following seven processing units: 1) a substrate storage facility, 2) a methane fertilization facility, 3) facilities for solid–liquid separation, 4) a digested manure storage facility, 5) a gas storage facility, 6) dehumidification and desulfurization facilities, and 7) biogas utilization facilities (e.g., biogas generators and gas boilers). Because this study was conducted to assess the potential for electricity supply from BGPs, major electrical equipment was selected from substrate storage, methane fertilization, and biogas utilization facilities.

For the measurement survey, an integrating wattmeter in breaker was monitored to identify the total power consumption of the BGP over a period of 24 h. The total power consumed by the electrical equipment in facilities other than the survey targets (referred to below as "other equipment") was calculated by subtracting the survey target equipment values from the values measured by an integrating wattmeter in breaker.

2.4. Leveling of power demand

To supply as much power as possible from the BGP to other power companies and customers, it was essential to minimize concurrent use of electrical equipment at the barn and the BGP as a way of ensuring stable power supply/consumption throughout the day. Accordingly, efforts were made in the study to level out peak loads assuming that concurrent use of equipment would be minimized.

3. Results and discussion

3.1. Simulation study

Based on the results of the simulation, Figs. 1 and 2 show temporal changes in power balance at the barn and the BGP. Farm A indicated a pattern of use, under which maximum power consumption at the entire barn (35.0 kW) was reached during milking time when a pipeline milker, a bulk cooler, and other machines were also in use. Ventilation fans were major consumers of power at 7.4–12.7 kW. Their operation concurrent with milking equipment took power use to the maximum level. On Farm B, maximum

Table 1
Outline of survey target farms without BGP.

Farm	No. of milking cows	Feeding management system	Power contract type three-phase	
			Type	Class
A	212	Free-stall housing	High voltage I	57 kW
B	181	Tie-stall housing	Low voltage	21 kW, 33 kW

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