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Research Paper

Proposal of a decision scheme for installing a cogeneration system considering disaster risks

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HIGHLIGHTS

- A planning scheme for a cogeneration system considering disaster risks was proposed.
- Our scheme is available for customers when considering profits and disaster risks.
- System operating simulations for four target buildings are performed.
- The installation of a cogeneration system is effective for some buildings under BCP consideration.

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ABSTRACT

This paper proposes a scheme, called the disaster-risk-weighted damage inequality, for a customer to perform introductory planning for a distributed generation system considering business continuity planning in a disaster case. To calculate this inequality, the relevant disaster risks are surveyed and system operating simulations for target buildings such as a hotel, a hospital, a large-scale office, and a collective housing building are performed by solving a mixed integer linear programming problem under the assumption that a cogeneration system is installed as a distributed generation system. Next, we determined the probabilities of a disaster occurrence and business interruption due to a disaster, the initial cost of the equipment, the running cost, and the reduction in running cost due to a cogeneration system installation. The cogeneration system was found to effectively reduce the running cost. Finally, the suggested inequality is calculated and determined whether it is satisfied. The result showed that cogeneration system installation very effectively reduces the running cost for a hotel, a hospital, and a large-scale office, compared to the tolerable amount of loss that is preliminarily determined by a customer.

1. Introduction

It is still fresh in our memories that the 2011 Great East Japan Earthquake resulted in the stoppage of the centralized generation system [1]. At that time, the lifeline system such as electricity supply and town gas supply were severely damaged. In the Tohoku area, long terms were required until recovered; for example, until 90% of system outage were recovered, it took 6 days for electricity supply and 35 days for gas supply [2].

Such stoppages resulted in paralysis of our daily lives as well as social functions and caused huge economic loss. After this earthquake disaster, business continuity planning (BCP), which is a guideline to ensure continued operation of a business, gained popularity in Japan.

Currently, as an electric power supply method during a blackout, the use of distributed generation systems is attracting attention from the perspective of BCP [3–7]. Kugetsu [3] showed that a distributed generation system consisting of a gas engine generator and other elements contributed to business and life continuity planning in addition to providing energy savings and CO_2 emission reduction. In particular, a cogeneration system (CGS) is an effective distributed generation system [6] as it can be used for generating electricity as well as for heating.

Disaster risks have been studied by several researchers [8–10]. They attempted to estimate the amount of damage economically. However, these studies do not consider the implementation of a tool that suggests an introductory plan for distributed generation systems.

To date, no study has considered and evaluated the disaster risk when implementing a distributed generation system. However, currently, in Japan, the number of buildings being equipped with a CGS from the viewpoint of BCP is increasing and this trend is

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Nomenclature

A	floor space (m^2)
a	gradient
C_{basic}	basic cost (JPY/yr)
C_{commod}	commodity cost (JPY/yr), (JPY/h)
$C_{int,15yr}$	initial cost in 15 years (JPY/(m_2-15 yr))
$C_{mnt,15yr}$	maintenance cost in 15 years (JPY/(m^2-15 yr))
C_{run}	running cost (JPY/yr)
$C_{run,15yr}$	running cost in 15 years (JPY/(m^2-15 yr))
E	electricity (kW)
E_{buy}	utility power (kW)
F	gas amount (m^3)
i	seismic intensity
j	time of a day ($0 \leqslant j \leqslant 23$)
L	tolerable amount of damage determined by a customer per an hour (JPY/h)
n	nth gas engine generator
N	total number of gas engines
P_{BI}	probability of business interruption
Q_{cool}	amount of heat for cooling (kJ)
Q_{ex}	amount of heat for exhaust heat (kJ)
Q_{heat}	amount of heat for air heating (kJ)
Q_{water}	amount of heat for hot water (kJ)
$T(i)$	outrage time period of blackout after a seismic intensity of i earthquake occurring (hr)
T_s	number of days for each season (days)
U_{basic}	unit price determined by contracted electricity (JPY/kW h)
U_E	unit price of electricity (JPY/kW h)
U_{gas}	unit price of gas (JPY/m^3)
x	input (m^3), (kW)
y	output (kW)

Greek

δ	0–1 integer variable

Subscript

d	demand
day	per a day
eqpt	equipment
ex	exhaust
jk	jacket water
gas	town gas
hr	per an hour
s	season (summer, winter, and middle season)
yr	per a year (annual)

expected to continue for the next decade. As it is now, in case a customer seriously considers introducing distributed energy systems to his/her buildings, an ongoing problem is that there is no guideline to choose suitable distributed energy systems with consideration of disaster risks.

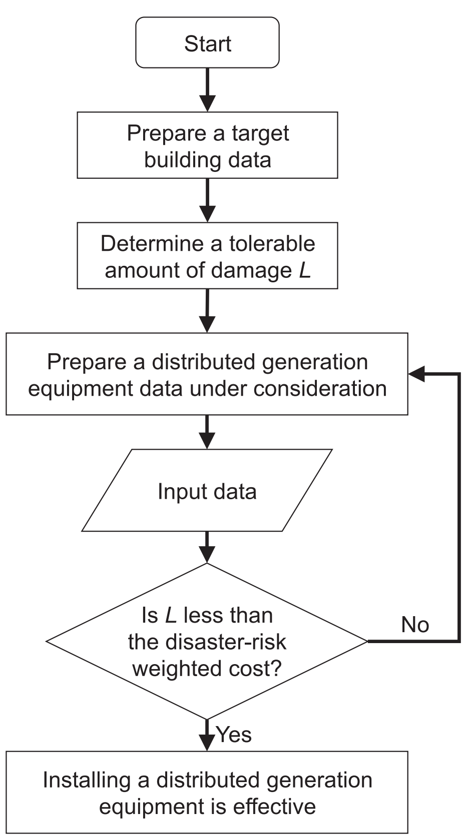

Fig. 1. A customer's making decision procedure proposed in this paper.

Therefore, this paper proposes "disaster-risk-weighted damage inequality" as a guideline to determine the equipment configuration for a distributed generation system for the first time. This inequality aims to show how to harmonize the daily energy management including the common utility grids and gas supply chain as well as distributed generation system and BCP in the case of the disaster.

Fig. 1 illustrates how to determine the equipment configuration using this inequality, which can judge whether a customer should introduce a distributed generation system while accounting for the disaster risk. Our proposed formula will be helpful for the customers to determine an introductory plan for a distributed generation system while promoting BCP in the case of a disaster. Lastly, assuming that installing CGS, we conducted case studies for four building uses—a hotel, a hospital, an office, and a collective housing building—and developed the respective evaluation tools. Then, we provided an introductory plan for a distributed generation system for each building type considered.

2. Survey of disaster risks

2.1. Survey of disaster probabilities and forms of damage

When we focus on BCP, it is important whether the business is stopped or not no matter how intensive disaster occurred. Therefore, this study simulated a single disaster risk regardless of the intensity of the disaster, the distance from the area where the disaster occurred, or the frequency of occurrence.

In this study, we assume a single disaster event to simplify the model, that is, we do not consider the effect of the following disaster event such as a tsunami after an earthquake. To evaluate the whole disaster risks, earthquake disasters, as well as the other disasters (man-made disasters, typhoons, equipment failures, etc.), were considered. Therefore, we first classified disasters into an earthquake disaster or other disasters, and then, surveyed the frequency of each disaster type.

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