QUANTITATIVE ANALYSIS ON RESILIENCE OF DISTRIBUTED ENERGY SYSTEMS CONSIDERING TYPICAL SUPPLY DISRUPTIONS IN JAPAN USING APPROXIMATE STOCHASTIC DYNAMIC PROGRAMMING

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Overview

Distributed energy systems (DES) , energy systems established next to customers, enable resilient energy supply and decentralize the risk of supply disruption compared to energy systems relying on the power grid. This study focuses on DES from the perspective of resilience and quantitively analyzes the optimal system and operation of DES considering typical supply disruptions in Japan caused by earthquake, typhoon and other reasons. Since DES should be economically efficient while they have to be resilient, supply disrupted situations would be stochastically integrated into normal situations, and the resilience of DES is evaluated based on the expected cost, according to the probability of supply disruption. Through optimizing calculation considering power outage risks, DES, specifically those based on the concept of cogeneration are both resilient and economically efficient. However, considering further risks, such as city gas supply disruption, the results suggest that there is a limit to the resilience of DES optimized for normal situations and that redundancy is required.

Methods

This study consists of three models. "Linear Programming Model" is used to calculate the optimal system and operation without considering supply disruption risks. The optimization results imply what kind of DES are desirable in order to maximize the economical efficiency. "Approximate Stochastic Linear Programming Model" is based on the concept of linear programming and stochastic state transition which stands for normal situation and supply disrupted situations is incorporated into the model. Since considering stochastic state transition leads to complex calculation, approximation is applied to reduce the complexity of the optimizing calculation. The third model is "Approximate Stochastic Dynamic Programming Model". This model is different from the other two models in that it is based on the concept of dynamic programming, while the other two models are based on linear programming. "Approximate Stochastic Dynamic Programming Model" considers stochastic state transition as "Approximate Stochastic Linear Programming Model" does and is used to calculate optimal system and operation considering stochastic supply disruption. Although approximation based on the concept of cutting plane method and convex hull helps reducing the complexity of the model, the problem is still too huge and complicated to be solved when the capacities of each equipments are not fixed. This is why the optimal system is calculated through "Approximate Stochastic Linear Programming Model" before solving "Approximate Stochastic Dynamic Programming Model".

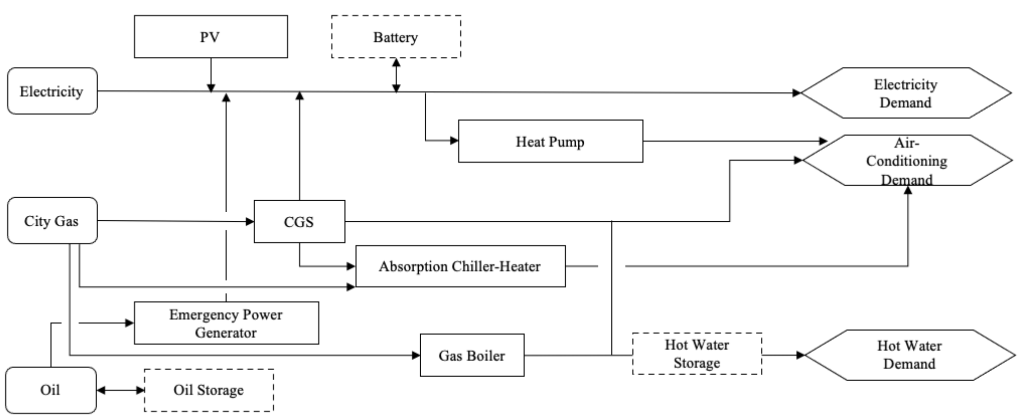

Fig.1 Energy System Flow

Without considering supply disruption risks, the system meets supply-demand balance by purchasing energy from outside of the system or supplying energy by itself. However, supply disruption risks considered, the system cannot manage to balance supply-demand in some cases, in which energy supply from outside of the system is disrupted and energy supply relies on internal energy supply. In the model, supply-demand balance is always satisfied, no

matter which case is considered, and the demand is suppressed in supply disrupted cases, instead of controling the energy supply. Demand suppression cost, the penalty for demand suppression, is added to the objective function and the models considering supply disruption risks are to minimize not just the energy supplying cost, but the sum of energy supplying cost and demand suppression cost.
The customer analyzed in this study is a commercial complex which consists of office, shop, hotel and hospital. Four types of demand are considered: electricity, cooling, heating and hot water. The probability of supply disruption and recovery are based on poisson distribution.

Results

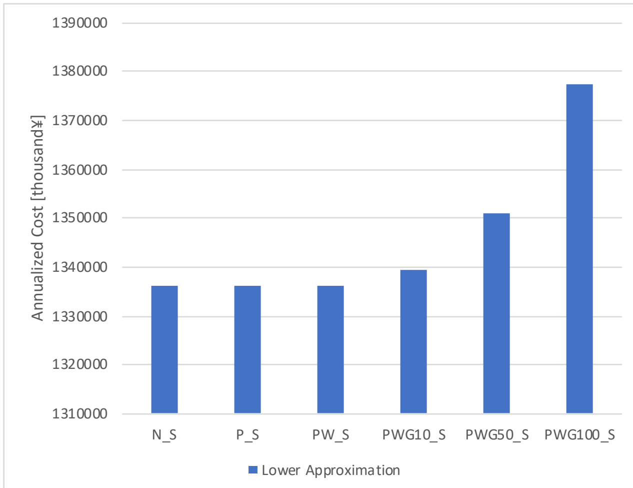

Fig.2 Annualized Cost

Focusing on maximizing economical efficiency(N_S), DES based on the concept of cogeneration turn out to be optimal. In such energy systems the amount of power purchase is slight, compared to that of city gas, and therefore whether considering power outage risks(P_S) does not make a difference to the result. However, considering further risks, such as city gas supply disruption(PWG10_S, PWG50_S, PWG100_S), the results imply that the two objectives might contradict each other: maximizing economical efficiency in normal situations and enhancing the resilience against supply disruption. Considering city gas supply disruption risks, emergency power generator and heat pump are required. By contrast, as calculation result of Linear Programming Model suggests, redundancy are to be reduced as much as possible to maximize economical efficiency. The degree of redundancy required differed according to how much risk gas supply disruption was assumed to be. As the probability of gas supply disruption gets higher, more redundancy is required and the expected cost increases.

Conclusions

In this study, the authors developed a model which enables us to optimize the configuration and the operation of DES from the perspective of economical efficiency and resilience. According to the results, as far as power outage risks are concerned, DES based on the concept of cogeneration is both economically efficient and resilient against supply disruption. However, the results varies depending on the risks concerned and the probability of each supply disruption situations. In particular, since cogeneration relies on gas supply, the risk of city gas supply disruption exerts a massive impact on the calculation system. Considering the risk of gas supply disruption, installation of emergency power generator and heat pump are required from the resilience perspective, whereas redundancy is regarded to be inefficient from the economical point of view. In order to improve the validity of the model, we have to take a closer look on the risk of gas supply disruption as well as power outage risk.

Acknowledgement

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