Calculation Method of Optimal Size of Battery Energy Storage Systems for a Microgrid Considering Coordinated Operation with Other Components

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1. Introduction

In microgrids, controllable generators (CGs) and battery energy storage systems (BESSs) are operated cooperatively to maintain the balance of power supply and demand.
On the other hand, BESS price is still high.
Therefore, sizing of BESS is an important factor in the design stage of microgrids.

The authors propose a sizing method of the BESS considering the power supply reliability and the economics of microgrid's operation.

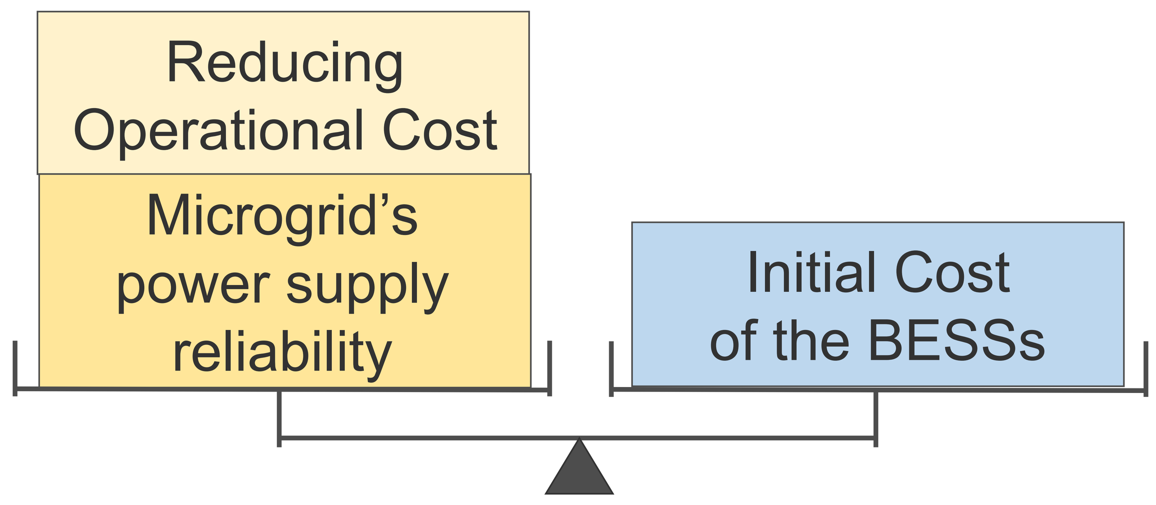


Fig. 1. Trade-off in the sizing of the BESSs

2. Problem Formulation

The target problem consists of an operation scheduling problem and a sizing of BESS problem; therefore, it has two-layer structure.

The target problem is formulated as bilevel problem.

Original problem

Upper-level: Operation scheduling

$$\min_{u,g,s}\{f_1(Q)+f_2(u,g,s)\}, \quad (1)$$
$$\text{s.t. } \Phi(u,g,s)=0. \quad (2)$$

u^*, g^*, s^* → Lower-level; Q^* → Upper-level

Lower-level: Sizing of BESS

$$\min_{Q} f_1(Q), \quad (3)$$
$$\text{s.t. } \varphi_k(Q)\le 0. \quad (4)$$

3. Problem Reformulation

① Applying the KKT approach translates the target problem from a bilevel problem to a single level one.

② In this problem, Eqs. (6)-(8) are omitted because it has already been considered in the upper-level objective function.

Reformulated problem (①)

$$\min_{\lambda,Q,u,g,s}\{f_1(Q)+f_2(u,g,s)\}, \quad (5)$$
$$\text{s.t. } \Phi(u,g,s)=0, \quad (2)$$
$$\varphi_k(Q)\le 0, \quad (4)$$
$$\nabla f_1(Q)+\sum_{k=1}^{K}\lambda_k\nabla\varphi_k(Q)=0, \quad (6)$$
$$\lambda_k\ge 0, \quad (7)$$
$$\lambda_k\varphi_k(Q)=0. \quad (8)$$

KKT conditions of lower-level problem.

Equations (6)−(8) have role of lower−level objective function.

Reformulated problem (②)

$$\min_{Q,u,g,s}\{f_1(Q)+f_2(u,g,s)\}, \quad (9)$$
$$\text{s.t. } \Phi(u,g,s)=0, \quad (2)$$
$$\varphi_k(Q)\le 0. \quad (4)$$

Q is dependent variable of u, g, s.

The target problem can be solved by operation scheduling methods.

- Q: Size of BESS.
- $u_{i,t}$: ON/OFF state of CGs.
- $g_{i,t}$: Output of CGs.
- s_t: Output of BESS.
- $f_1(Q)$: Initial cost of BESS.
- $f_2(u,g,s)$: Operation cost of a microgrid.
- $\Phi(u,g,s)$: Upper-level constraints.
- $\varphi_k(Q)$: Lowe-level constraints.
- k: Constraints number in lower-level.
- λ_k: Lagrange multipliers in lower-level determined by active constraints.

4. Solution of the Reformulated Problem

In the reformulated problems, once u is determined, Q, g, s can be derived by **the quadratic programming (QP)**.
Proposed method determines u by **the binary particle swarm optimization (BPSO)** and the other variables by the **QP**.
The solutions of PSO depends on stochastic search mechanism.
The proposed method limits influence of stochastic search only to u.

Table 1. The kinds of variables treated by each solution methods.

Solution method	BPSO-QP (proposed method)	PSO without KKT approach	PSO with KKT approach
Variables (treated by PSO)	u	Q, u, g, s	u, g, s

5. Numerical Simulations

Numerical Simulation Conditions

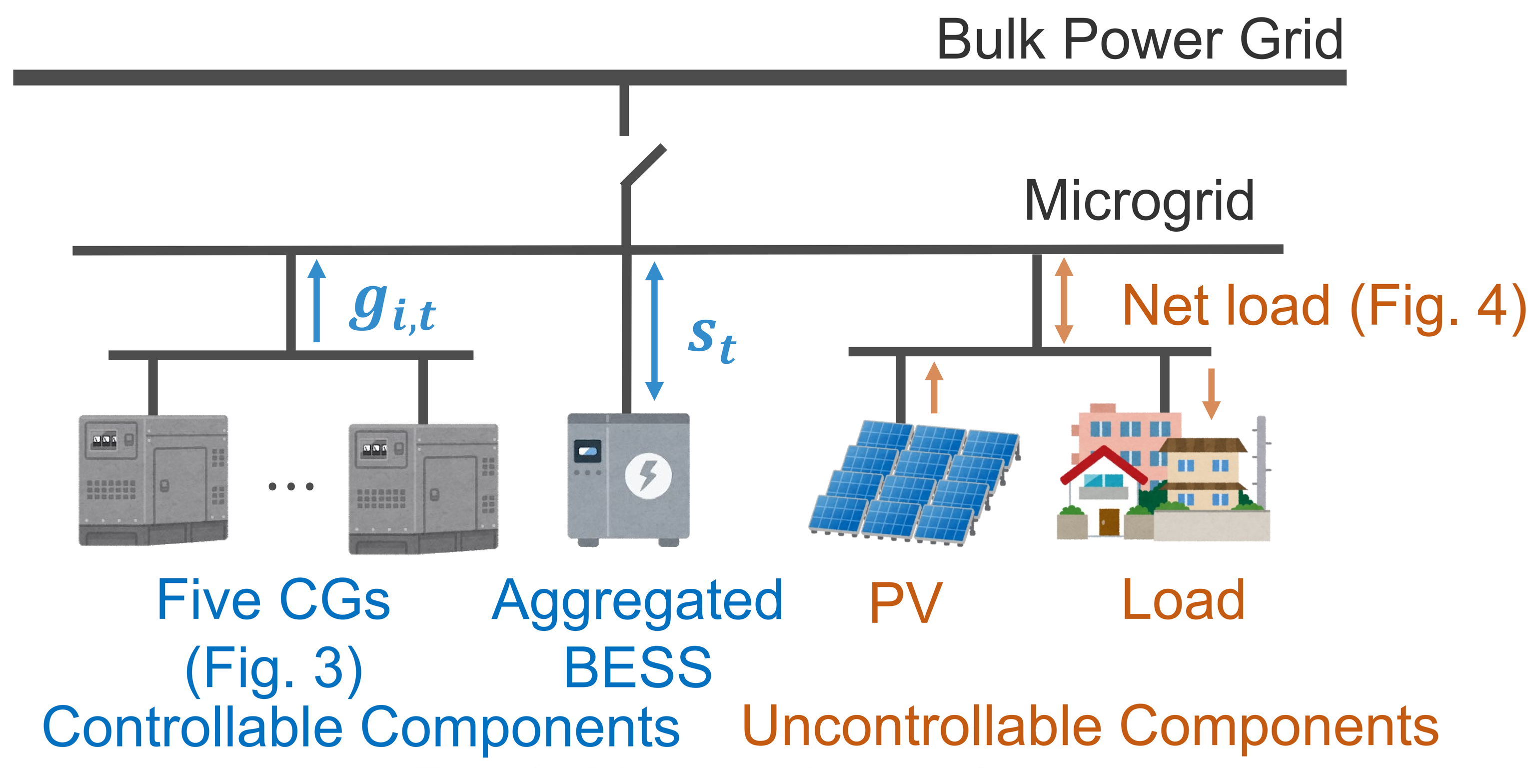


Fig. 2. Microgrid model

Numerical simulations were performed based on the microgrid model (Fig. 2).
The unit price of the aggregated BESS was set to 20,000JPY/kWh.
※This setting is lower than the current price with reference to literature.

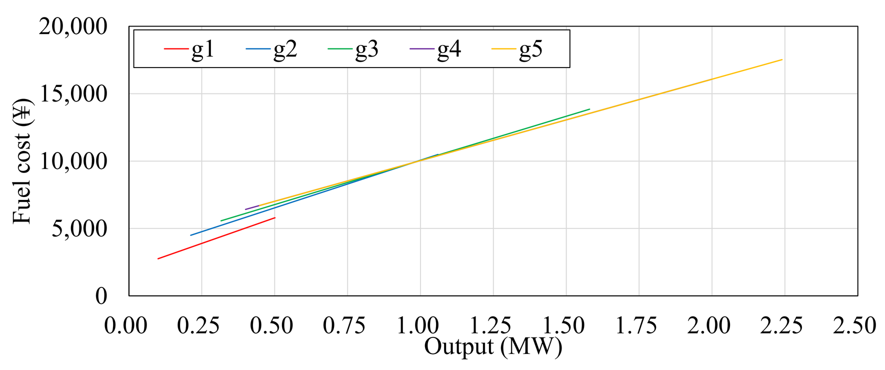


Fig. 3. Specifications of CGs

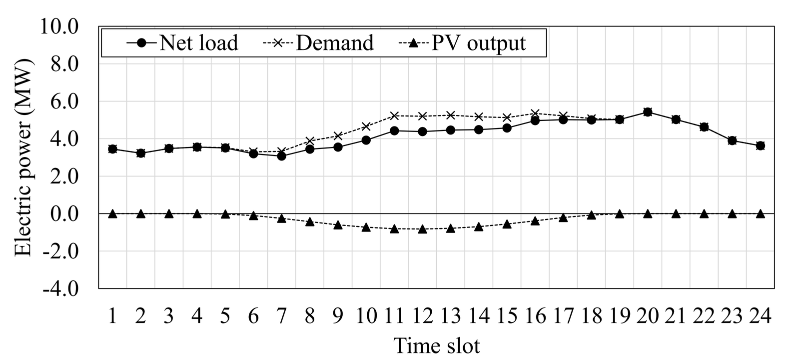
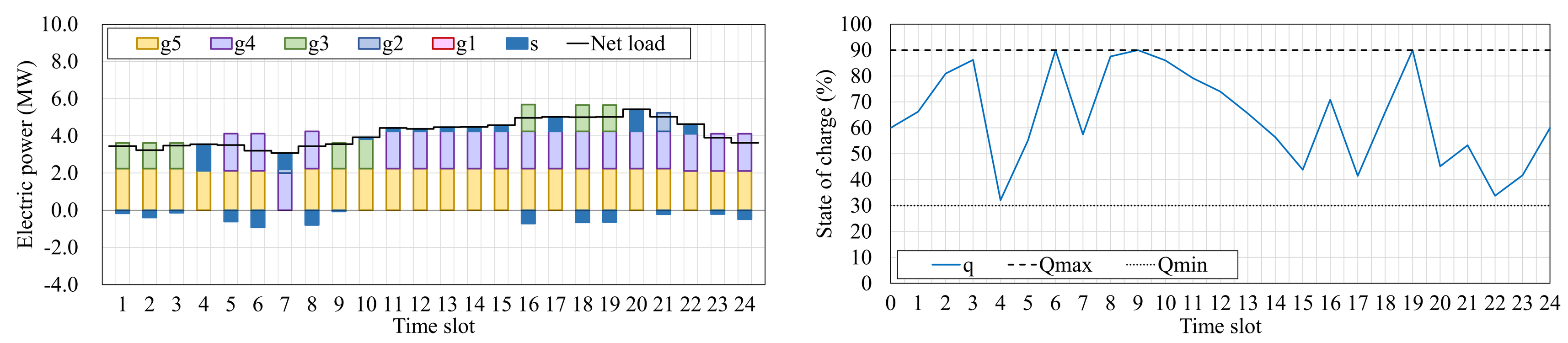


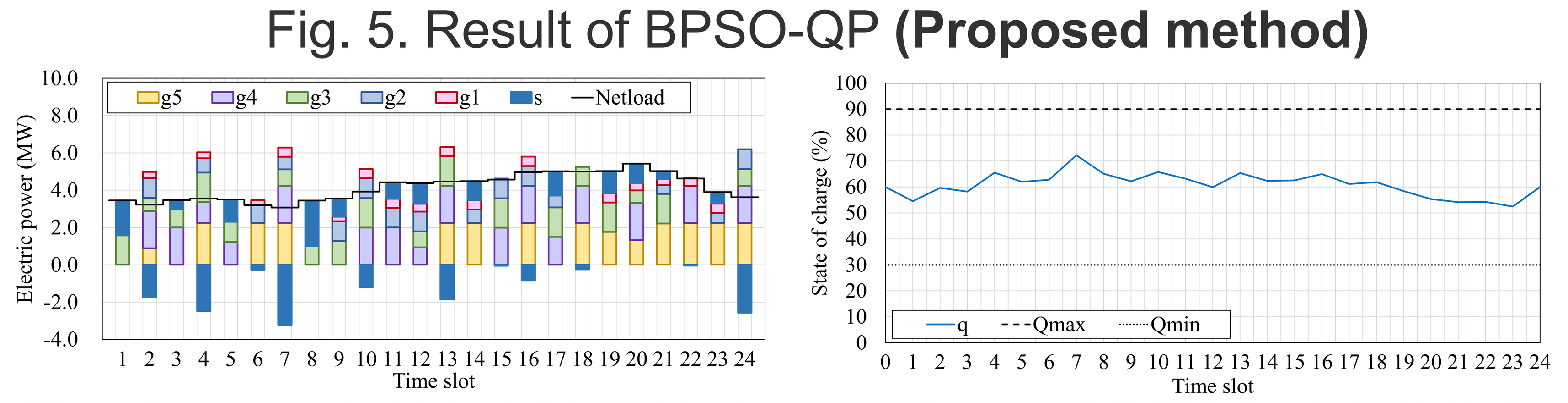
Fig. 4. Profile of uncontrollable components

Numerical Simulation Results



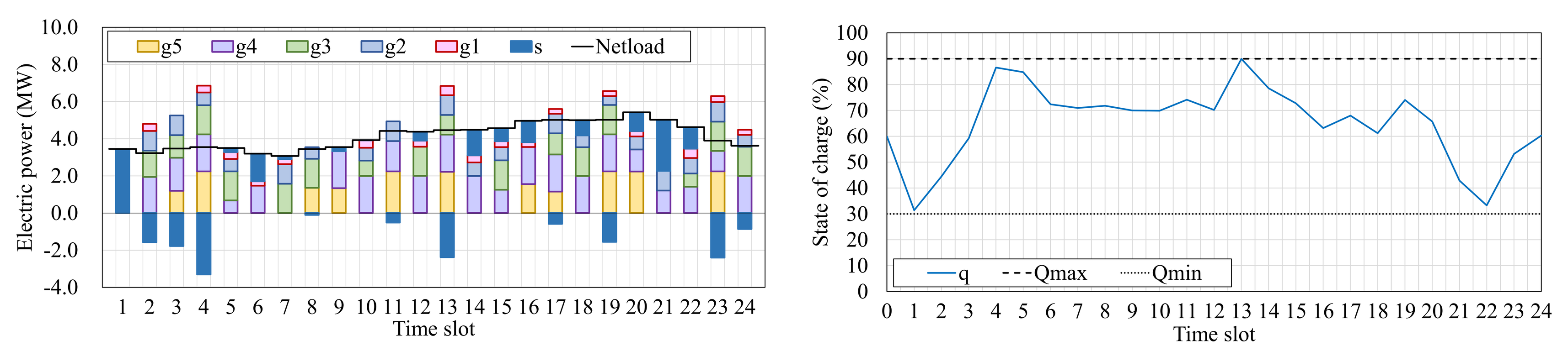
Total cost: 823,713JPY/day **Size of BESS: 2.65MWh**

Fig. 5. Result of BPSO-QP **(Proposed method)**



Total cost: 1,099,240JPY/day **Size of BESS: 34.1MWh**

Fig. 6. Result of PSO without KKT approach



Total cost: 991,236JPY/day **Size of BESS: 12.1MWh**

Fig. 7. Result of with KKT approach

The BPSO-QP led the best results in the three.
The results shows that fewer kinds of variables determined by the PSO obtained better solutions.

6. Conclusions

The sizing of BESS problem is formulated as a bilevel problem.
The KKT approach made it possible for us to apply the operation scheduling method and led to better results.
In future works, how to handle larger scale problems is considered.