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Electricity adjustment for capacity market auction by a district heating and cooling system

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HIGHLIGHTS

- Proposes methods for electricity capacity market auction with DHCs.
- Models electricity adjusting capacity provision and electricity adjustment.
- Models and evaluates an actual DHC system.
- Methods had low additional cost relative to cost of normal operation.

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ABSTRACT

Power grids connected to renewable energy sources must cope with fluctuating output by those sources. One method to do so is for the power grid company to accept bids to increase grid stability. These bids are accepted via capacity market auction of increasing grid stability. These offers are to increase the maximum power capacity by using power stations (both utility and non-utility stations) and by reducing electricity consumption via demand response. One candidate for achieving this is a district heating and cooling (DHC) system installed with combined heat and power. However, the electricity adjustment (EA) operation needed by the DHC for the auction is complicated because the system consists of boilers, water heaters, chillers, generators, and other items. To investigate the possibility of using DHC systems for capacity market auctions, this paper proposes two models for operating a DHC system: electricity-adjustment capacity (EAC) provision and EA operation. In addition, to develop methods for evaluating the cost of the proposed operational methods, a model DHC system is formulated with an actual DHC system as a basis. Using the models, numerical simulations are conducted by particle swarm optimization. Then, the running costs of EAC, EA, and normal operation are calculated. The results show that the running costs of the proposed operations are relatively stable by day and season, not varying beyond the range of ± 10%. Nevertheless, the running costs in spring and fall are be lower than those in summer and winter. The cost of providing EAC is no more than 1% the cost of normal operation, and the cost of EA itself is no more than 2% that of normal operation.

1. Introduction

Governments are implementing renewable energy policies with the aim of preventing global warming and reducing energy problems [1,2]. Photovoltaic systems and wind power plants are promising candidates for renewable energy; however, their inherent fluctuations reduce power-grid stability. Demand response (DR), which entails changing electricity consumption on the demand side in response to the grid operator's request, is a potential solution to fluctuating generation. Typically, incentives will be paid to a consumer by the grid operator to change consumption amount. DR has been extensively discussed in the literature [3–6]. In a similar way, capacity market auctions were introduced for capacity providers who can adjust power capacity and generate electricity according to a power grid's request. Typically, the group targeted by DR is electricity consumers; in contrast, the targets of capacity market auctions are power stations (utility and non-utility), electricity storage plants, and capacity provided by demand reduction. Open markets exist in many countries, including the United Kingdom, Russia, and the United States (via the regional transmission organization PJM) [7–11]. Japanese electricity companies issued a public call

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Nomenclature

Abbreviations

CHP combined heat and power
COP coefficient of performance
DH district heating
DHC district heating and cooling
DR demand response
EA electricity adjustment
EAC electricity-adjustment capacity
EDC economic dispatch control
ESS energy storage system
LFC load-frequency control
MILP mixed integer linear programming
Op. 1 normal operation
Op. 2 EAC preparatory operation
Op. 3 EA operation
PSO particle swarm optimization
RE renewable energy

Indices

t time of simulation
n equipment number

Constants

G_p gas price [JPY/m^3]
P_p electricity price [JPY/kWh]
$p_d(t)$ station load [kW]
p_{MAX} maximum transmission power at interconnecting point [kW]

Parameters

$s_d(t)$ heating demand [tonne/h]
$cw_d(t)$ cooling demand [GJ/h]
t_{start} start time of adjustment
t_{end} end time of adjustment
t_n^{start} start-up time of equipment n
$x_{g,1}^{min}$ lower input limit of equipment no. 1 [m^3/h]
$x_{g,3}^{min}$ lower input limit of equipment no. 3 [m^3/h]
$x_{1,2}^{min}$ lower output limit of equipment no. 1 [tonne/h]
cap_{target} amount of adjustment capacity preparation [kW]

Variables

$Cost_{day}$ running cost per day [JPY]
$g(t)$ gas consumption [m^3/h]
$p(t)$ electricity consumption [kW]
$s_g(t)$ steam generation [tonne/h]
$cw_g(t)$ cold water generation [GJ/h]
$f_{i,n,j}$ conversion efficiency from $x_{i,n}(t)$ to $x_{n,j}(t)$ of equipment n [–]
$x_{i,n}$ input i to equipment n
$x_{n,j}$ output j from equipment n
$p_{cap}(t)$ transmission power at interconnecting point at Op. 2 [kW]
$x_{i,n}^{start}$ input of equipment n at start-up time

for a capacity market auction in the final quarter of 2016 [12]. The categories requested include (i) online very-high-speed response for load-frequency control (LFC), (ii) online high-speed response for supply/demand balance, and (iii) online or offline response for supply/demand balance in response to severe climate conditions that might occur only once per decade on average. Category (iii) is interesting because it does not require high-speed response, which makes it open to a wide range of energy providers. Candidates for this include district heating (DH) and district heating and cooling (DHC) systems installed with combined heat and power (CHP), which cannot respond very quickly because they have thermal energy equipment to provide heating and cooling energy.

DH and DHC systems should have high potential for this use case. They are widely used by energy utility companies in many districts. In Japan 140 DH or DHC systems provided 23 PJ of energy in 2011 [13]. Because CHP increases fuel efficiency sharply, CHP is often installed with DHC systems. As evidence of this, the share of DH or DHC systems with CHP in Denmark is roughly 80% [14]. Therefore, DHCs should have large potential for category (iii).

Operation of DH or DHC systems is complicated because they consist of thermal and electrical equipment. There are researches in terms of its optimization, for example, optimization of size and operation of DHC systems for districts or neighborhood level[15–17], optimal layout and operation of CHP assuming actual city [18], optimization of distributed energy system considering transport of water [19], and cost minimization considering influence of fuel price [20]. Additionally, some papers consider an electricity market. Powell et al., Strechiene et al. and Rolfsman et al. assumed a district energy system with thermal energy storage in a real-time market [21–23], Moshkin et al. and Dimoulkas et al. optimized a DH system in a electricity market with stochastic behavior of electricity market prices [24,25] and Wang et al. considered CHP, REs and ESS and minimized thermal and electricity cost [26]. Bidding strategies in an electricity market was researched by Riveros et al. [27].

Recent papers considered DR for optimization including; stochastic behavior of demand, market price, and wind speed [28], building thermal inertia [29], CHP based micro-grid [30,31], ultra-low temperature DH systems [32] and short-term scheduling of heat and power generators [33]. And there are papers targeting grid balancing in situations of high share of REs in electricity grid. Mitridati et al. researched a dispatch problem assuming large number of CHP and wind powers [34]. Bachmaier et al. researched spatial distribution of thermal ESS in urban areas [35]. Sorknaes et al. discussed decrease of operating hours of CHP because of increase of RE, and increase of the economic feasibility by participating in the electricity balancing tasks [36]. Stadler discussed DR with CHP for grid stability [37], and Ostergaard studied grid stability by CHP and heat pump [38].

In contrast, cost evaluation of using a DHC system for the capacity market auction involves two types of models for meeting requests by the power grid: waiting models and responding models. The research mentioned above considered operation of a whole microgrid or of set of houses, but not operation of a DHC system. System-wide optimization could minimize an objective function of the system. However, in real

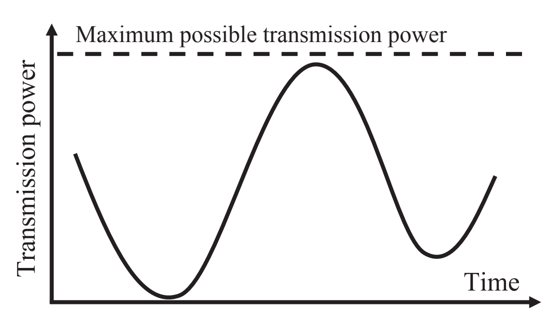

Fig. 1. Transmission power in normal operation (Op. 1).