LP-based Mathematical Model for Optimal Microgrid Operation Considering Heat Trade with District Heat System

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Abstract

Since Combined Heat and Power (CHP) generation produces heat and electricity energy concurrently, it can be a major source in the microgrid. Especially, since electric and heat energy networks are coupled at CHP generation in the microgrid. For this reason, microgrid operation should consider electric and heat energy together when the CHP generation is included. This paper presents a mathematical model for optimal operation of a microgrid including the CHP generation and heat trading with a district heat system (DHS). The relationship of optimal variables and system parameters is modeled by linear programing (LP). The case study is performed to show the validation of the optimal model.

Keywords: *Microgrid, optimal operation, combined heat and power (CHP) system, heat trade, district heat system (DHS)*

1. Introduction

A microgrid is a small scale power system, which has a private power grid. Since it includes renewable energy sources such as wind turbine generation systems and photovoltaic generation system as major power sources, it is evaluated as evaluated as a green energy system. Currently, to commercialize microgrid, many projects have been performed in many countries [1-4].

Generally, the microgrid is operated by two modes: the grid-connected mode and the islanded mode. In the grid-connected mode, the microgrid is interconnected with a power system and can trade its surplus/short power with the power system; economical operation is the important issue. In the islanded mode, microgrid is operated by only its generation without any interconnection with the power system [5]; frequency and voltage control is a main issue.

Combined Heat and Power (CHP) generation is an energy source of microgrid operation; it produces heat and electricity energy concurrently. In addition, total energy efficiency of CHP generation is high and various CHP generation systems, such as fuel cell systems and micro-turbine generators, can be applied. For this reason, CHP generation can be a major energy source in the microgrid. Especially, electric and heat energy networks are coupled at CHP generation in the microgrid. For this reason, many research works have been performing [6-10]. Meanwhile, heat trade with the district heat system (DHS) can be a good topic for

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economic operation of heat energy. For this reason, the optimal operation model of microgrid including CHP generation considering heat trade with the DHS.

This paper deals with optimal operation of a microgrid having CHP generation; the optimal operation considers the heat energy network as well as the electricity energy network together. In addition, the model includes heat trade with a district heat system (DHS). The mathematical model for optimal operation of the microgrid is modeled by linear programing (LP). The validation of proposed the model for optimal microgrid operation is shown through case study; the case study result is analyzed.

2. Microgrid

A microgrid is composed of distributed generation systems (DGs), distributed storage systems (DGs), and loads. DG can be divided into the controllable generators such as diesel generators and CHP generation, and uncontrollable renewable energy generators such as PV systems. Loads are composed of heat loads and electrical loads. The microgrid is connected with a power grid for trading electric energy and a DHS for trading heat energy. The configuration of the microgrid is as shown in Figure 1 [11].

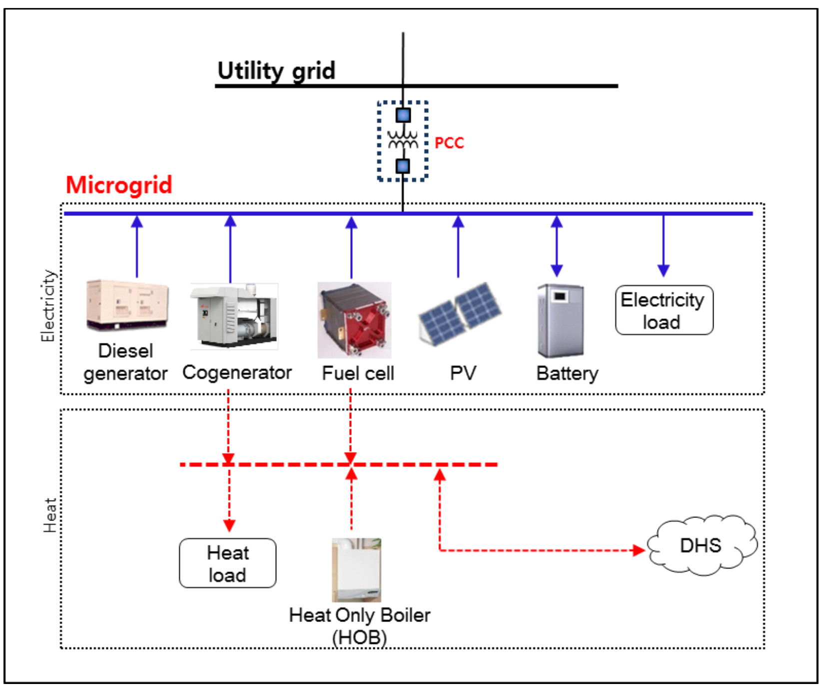

Figure 1. Microgrid configuration

3. Mathematical Model for Optimal Microgrid Operation

In this paper, a mathematical model for optimal operation of microgrid including CHP generation based on LP is proposed. The proposed object function is established to minimize the cost of microgrid operation as shown in Eq. (1).

$$C_{MG}\left(M^{e}_{CHP_1}(t)\ldots M^{e}_{CHP_I}(t), M_{DG_1}(t)\ldots M^{e}_{DG_J}(t), M_{HOB_1}(t)\ldots M^{e}_{HOB_K}(t), M^{e}_{BUY}(t), M^{e}_{SELL}(t), M^{h}_{BUY}(t), M^{h}_{SELL}(t)\right)$$

$$= \sum_{i=1}^{I}(C_{CHP_i}\cdot M^{e}_{CHP_i}(t)) + \sum_{j=1}^{J}(C_{DG_j}\cdot M_{DG_j}(t)) + \sum_{k=1}^{K}(C_{HOB_k}\cdot M_{HOB_k}(t)) + \left(C^{e}_{BUY}(t)\cdot M^{e}_{BUY}(t)\right) - \left(C^{e}_{SELL}(t)\cdot M^{e}_{SELL}(t)\right) + \left(C^{h}_{BUY}(t)\cdot M^{h}_{BUY}(t)\right) - \left(C^{h}_{SELL}(t)\cdot M^{h}_{SELL}(t)\right) \quad for\ 1 \le t \le T$$

$$\min C_{MG}(t), \tag{1}$$

where

t = the identifier of operation interval
T = the number of operation intervals
i = the identifier of CHP generation
I = the number of CHP generation
j = the identifier of diesel generator (DG)
J = the number of DG
k = the identifier of heat only boiler (HOB)
K = the number of HOB
e = the identifier of electric energy
h = the identifier of heat energy
C_{CHP_i} = the electric energy production cost of the i^{th} CHP [won/kWh]
C_{DG_j} = the electric energy production cost of the j^{th} DG [won/kWh]
C_{HOB_k} = the heat energy production cost of the k^{th} HOB [won/kWh]
$C^{e}_{BUY}(t)$ = the buying price from the power grid at t [won/kWh]
$C^{e}_{SELL}(t)$ = the selling price to the power grid at t [won/kWh]
$C^{h}_{BUY}(t)$ = the buying price from the DHS at t [won/kWh]
$C^{h}_{SELL}(t)$ = the selling price to the DHS at t [won/kWh]
$M^{e}_{CHP_i}(t)$ = the electric energy production amount of the i^{th} CHP at t [kWh]
$M_{DG_j}(t)$ = the electric energy production amount of the j^{th} DG at t [kWh]
$M_{HOB_k}(t)$ = the heat energy production amount of the k^{th} HOB at t [kWh]
$M^{e}_{BUY}(t)$ = the amount of electric energy purchased from the power grid at t [kWh]
$M^{e}_{SELL}(t)$ = the amount of electric energy sold to the power grid at t [kWh]
$M^{h}_{BUY}(t)$ = the amount of heat energy purchased from the power grid at t [kWh]
$M^{h}_{SELL}(t)$ = the amount of heat energy sold to the power grid at t [kWh]

Constraints are defined as follows. CHP generation should be operated between minimum generation and maximum generation, as shown in Eq. (2).

$$\min[M^{e}_{CHP_i}(t)] \le M^{e}_{CHP_i}(t) \le \max[M^{e}_{CHP_i}(t)] \tag{2}$$

Similarly, Eq. (3) and (4) mean the generation constrains of DG and HOB.

$$\min[M_{DG_j}(t)] \le M_{DG_j}(t) \le \max[M_{DG_j}(t)] \tag{3}$$

$$\min[M_{HOB_k}(t)] \le M_{HOB_k}(t) \le \max[M_{HOB_k}(t)] \tag{4}$$

Equation (5) shows the balance between electric energy supply and demand.

$$\sum_{i=1}^{I} M^{e}_{CHP_i}(t) + \sum_{j=1}^{J} M^{e}_{DG_j}(t) + \sum_{l=1}^{L} M^{e}_{RDG_l}(t) + M^{e}_{BUY}(t) - M^{e}_{SELL}(t) = M^{e}_{LOAD}(t) \quad (5)$$

where
$l =$ the identifier of renewable distributed generation (RDG)
$L =$ the number of the RDG
$M^{e}_{RDG_l}(t) =$ the output of RDG at t [kWh]
$M^{e}_{LOAD}(t) =$ the electricity load at t [kWh]
$M^{e}_{LOAD}(t) =$ the electricity load at t [kWh]

The relationship between electricity and heat produced from the CHP generation is as follows [4].

$$M^{h}_{CHP_i}(t) = (1/k) \cdot M^{e}_{CHP_i}(t), \quad (6)$$

where
$k =$ the heat and electric power ratio
$M^{h}_{CHP_i}(t)$ = the heat energy production amount of the i^{th} CHP at t [kWh]

Equation (7) shows the balance between heat supply and demand.

$$\sum_{i=1}^{I} M^{h}_{CHP_i}(t) + \sum_{k=1}^{K} M^{k}_{HOB_k}(t) + M^{h}_{BUY}(t) - M^{h}_{SELL}(t) = M^{h}_{LOAD}(t), \quad (7)$$

where
$M^{h}_{LOAD}(t) =$ the heat load at t [kWh]

4. Case Study

4.1 Operation condition

In this paper, we assume 24 intervals for optimal microgrid operation. Data of generation systems is shown in Table 1. Loads are composed of a lumped electric load and a lumped heat load as shown in Figure 2.

Table 1. Data of energy sources

Item	DG A	DG B	CHP A	CHP B	HOB
Cost (won/kWh)	135	140	150	145	80
Minimum production capacity (kWh)	0	0	30	50	0
Maximum production capacity (kWh)	100	80	60	100	80
the heat and electric power ratio	-	-	1.2	0.8	-

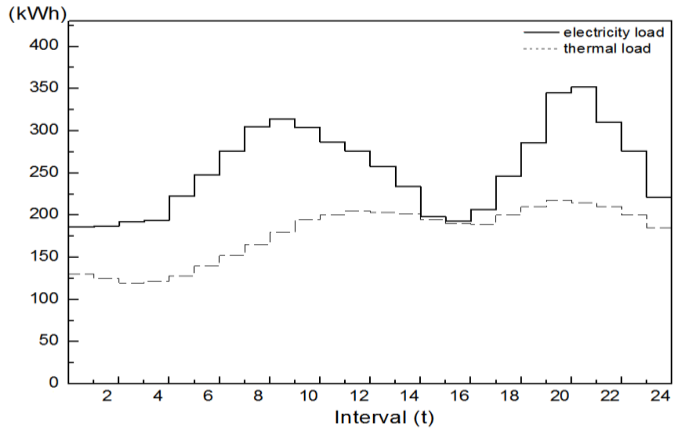

Figure 2. Electricity and heat load (Input data)

This paper is considering heat energy supply from the district heating (DH) network [12]. Trading price of electric energy is real-time trading prices as shown in Figure 3. In addition, trading price of heat energy is shown in Figure 4.

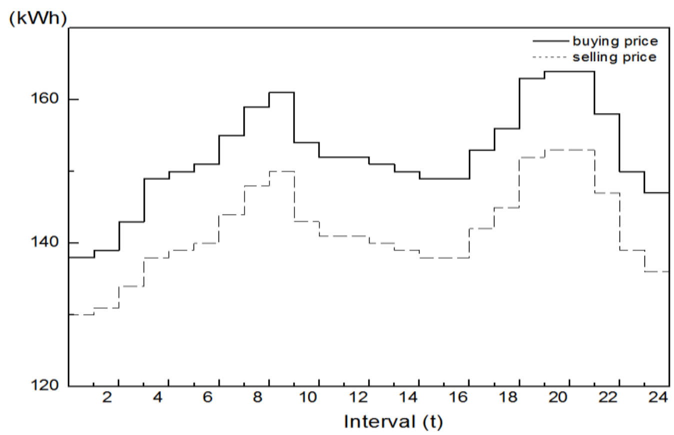

Figure 3. Trading price of electric energy

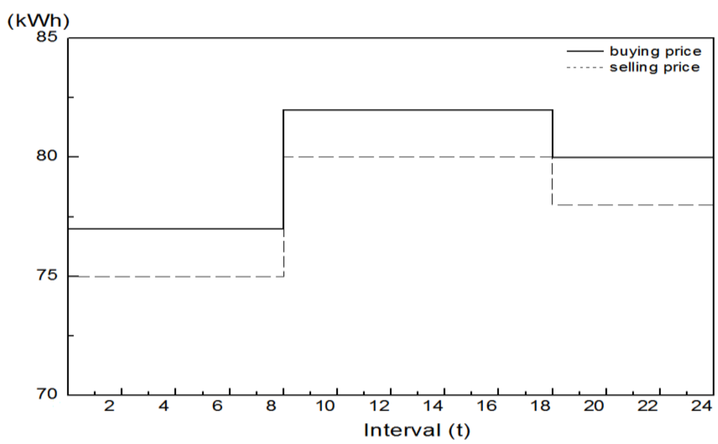

Figure 4. Trading price of heat energy

Figures 5 and 6 show the optimal electric and heat generation as the simulation result.

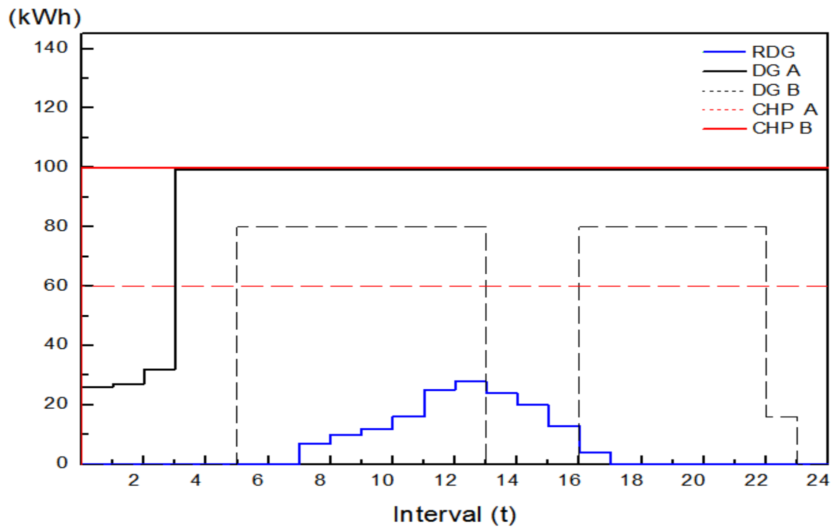

Figure 5. Optimal electric energy generation

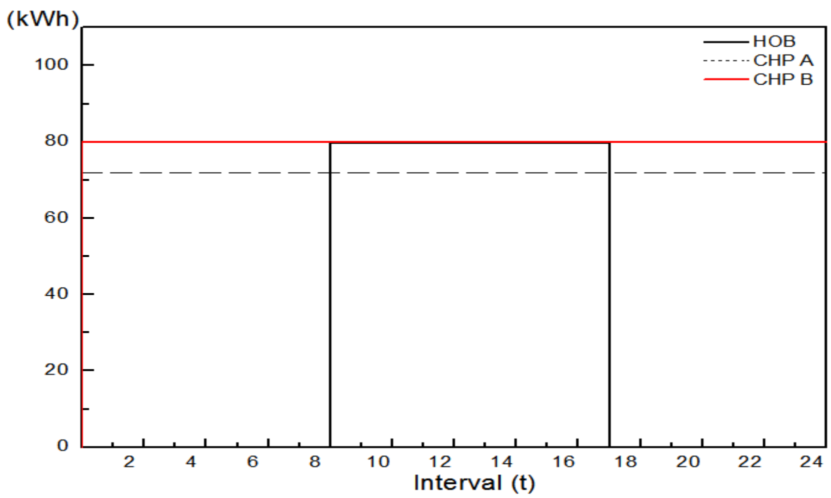

Figure 6. Optimal heat production

As shown in the figures, although CHP A and CHP B have high cost than DG A and DG B, they have high priorities than DG A and DG B because their heat costs are lower than the HOB. It seems that their operation is focused on the heat energy.

Figure 7 shows trading amount of electric energy with the power grid and Figure 8 shows trading amount of heat energy with the DHS, respectively.

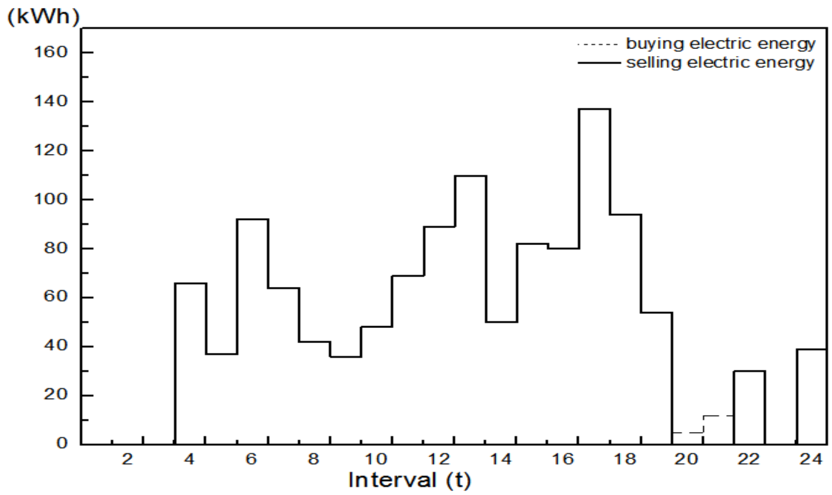

Figure 7. Optimal trading amount of electric energy

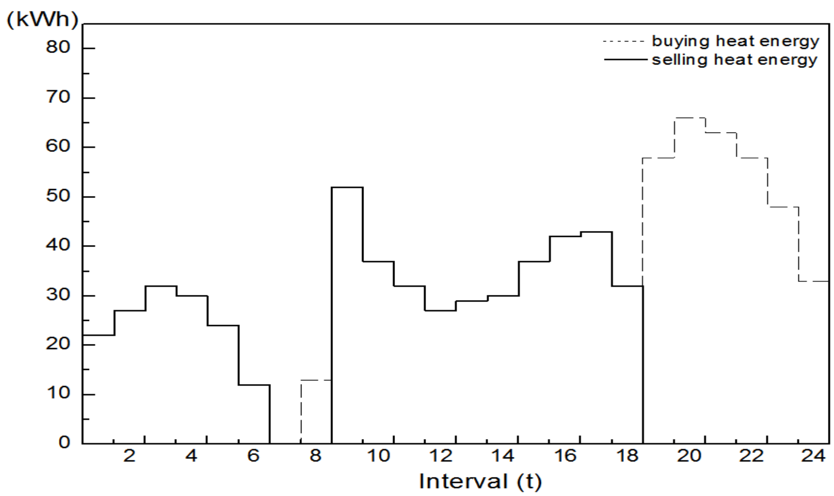

Figure 8. Optimal trading amount of heat energy

As shown in Figure 7, we can see that trading electric energy with the power grid is performing by the economic viewpoint based on generation costs and trading prices. In the case of heat energy, although costs of CHP generator are higher than cost of diesel generators, CHP generators produce electric and heat energy fully for heat energy as shown in Figures 5 and 6. Surplus heat energy is trade to the DHS. We can see that heat energy is also operated by the economic viewpoint based on heat production and trading prices as shown in Figure 8.

From the result of microgrid operation, it is shown that the microgrid is operated by the economic viewpoint based on the proposed operation model.

5. Conclusion

In this paper, a mathematical model for optimal operation of a microgrid considering heat trade between DHS has been proposed. The relationship of optimal variables and system parameters has been modeled by linear programing. A case study has been performed in order to show the validation of the model.

As a future work, models of electric and heat energy storage systems will be added to the proposed model.

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