Operation Scheduling in a Commercial Building with Chiller System and Energy Storage System for a Demand Response Market

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냉각 시스템 및 에너지 저장 시스템을 갖춘 상업용 빌딩의 수요자원 거래시장 대응을 위한 운영 스케줄링

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Abstract The Korean DR market proposes suppression of peak demand under reliability crisis caused a natural disaster or unexpected power plant accidents as well as saving power plant construction costs and expanding amount of reserve as utility's perspective. End-user is notified a DR event signal DR execution before one hour, and executes DR based on requested amount of load reduction. This paper proposes a DR energy management algorithm that can be scheduled the optimal operations of chiller system and ESS in the next day considering the TOU tariff and DR scheme. In this DR algorithm is divided into two scheduling's; day-ahead operation scheduling with temperature forecasting error and operation rescheduling on DR operation. In day-ahead operation scheduling, the operations of DR resources are scheduled based on the finite number of ambient temperature scenarios, which have been generated based on the historical ambient temperature data. As well as, the uncertainties in DR event including requested amount of load reduction and specified DR duration are also considered as scenarios. Also, operation rescheduling on DR operation day is proposed to ensure thermal comfort and the benefit of a COB owner. The proposed method minimizes the expected energy cost by a mixed integer linear programming (MILP).

요 약 한국의 수요자원(Demand Response, DR) 거래시장은 자연재해 또는 예기치 않은 발전소 사고로 인한 전력수급 위기 시 최대수요를 억제하며, 발전소 건설비용 절감 및 운영예비력 확보를 위한 목적으로 운영되고 있다. 수요자원 거래시장에 참여한 수용가는 전력거래소로부터 수요 감축 1시간 전 급전지시를 통보 받으며, 요청된 수요자원 감축을 통하여 기본급과 실적금을 정산 받는다. 본 논문에서는 냉각 시스템과 ESS을 갖춘 수용가가 계시별요금제와 수요자원 거래시장에 동시 참여 시, 최적 운영계획 수립을 위한 DR 에너지관리 알고리즘을 제안 하였다. 제안된 알고리즘은 주위온도 예측오차가 있는 전일 운영 스케줄링과 DR 운영일 리스케줄링의 두 가지 운영 스케줄링으로 구성된다. 전일 운영 스케줄링의 경우, 냉각 시스템, ESS의 운영스케줄링은 과거 주위온도 데이터를 기반으로 생성된 주위온도 시나리오와 불확실한 DR감축 시나리오에 의해 결정된다. 또한 DR 운영일에 대한 리스케줄링은 수용가의 DR 수익과 건물내부 열쾌적성이 보장되며 제안된 방법은 혼합 정수 선형 프로그래밍(Mixed Integer Linear Programming, MILP)에 의해 기대 에너지 비용을 최소화한다.

Keywords : Chiller System, Demand Response, Energy Management System, Energy Storage System, MILP

1. Introduction

Smart grid technology promotes deregulation policies in the electric power companies. It would provide business opportunities of market participation to end-users such as commercial buildings (COBs), residences, and industrial facilities. This is the key Smart grid technology promotes deregulation policies in the electric power companies. It would provide business opportunities of market participation toend-users such as commercial buildings (COBs), residences, and industrial facilities. This is the key concept of demand response (DR) [1-2]. DR is defined by the U. S. Department of Energy (DOE) in its February 2006 report to Congress and subsequently adopted by the Federal Energy Regulatory Commission (FERC) is stated as [3]: "Changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized."

The Korean DR market proposes suppression of peak demand under reliability crisis caused a natural disaster or unexpected power plant accidents as well as saving power plant construction costs and expanding amount of reserve as utility's perspective. End-user is notified a DR event signal (central load dispatching) DR execution before one hour, and executes DR based on requested amount of load reduction. End-user has settlement for DRRs participating in the Korean DR market; reward for waiting capacity (kW) and reward for actually energy reduced (kWh). Reward for waiting capacity (kW) is annually contracted through a bedding system. Reward for actually energy reduced (kWh) are paid to end-user according to total executed load reduction. However, end-user cannot execute 80% of requested load reduction based on the contract capacity, DR penalty must be paid to utility company. This paper proposed a DR energy management algorithm that can be scheduled the optimal operations of chiller system and ESS in the next day considering the TOU tariff and DR scheme. In this DR algorithm is divided into two scheduling's; day-ahead operation scheduling with temperature forecasting error and operation rescheduling on DR operation. The proposed method minimizes the expected energy cost by a mixed integer linear programming (MILP).

2. Scenarios for Uncertainties

The optimal operations of chiller system and ESS are scheduled for maximum DR reward and avoiding penalty considering uncertain environments through TOU tariff and the Koran DR market as follows.

2.1 DR Event

In the Korea DR scheme, occurrence of DR event is informed from the utility company only 1 hour before the execution with the information of DR duration and requested curtailment (in kW, less than or equal to the waiting DR capacity) [4]. It is very difficult to know when a DR event happens from end-user. Some DR resources such as chiller system and ESS can be achieved their energy reduction during DR events. End-user should schedule the optimal DR resources operation for minimal energy cost regardless of DR events. A variety of DR events including DR duration and requested curtailment with high occurrence probability are considered as scenarios to the mathematical formation.

2.2 Ambient temperature

On a hot day, the chiller system should be heavily operated to maintain thermal comfort for indoor temperature. Namely, power consumption of chiller system strongly depends on the ambient temperature. The ambient temperature also affects the DR event. In fact, the DR events tend to happen in hot days [5]. That is, error included in the ambient temperature

forecast could cause deterioration in thermal comfort, or insufficient DR contribution. It is important that the DRR operation should be robust for the ambient temperature forecast errors. Ambient temperatures are considered as scenarios to mathematical formulation.

3. Concept of the proposed DR scheme

If end-users are previously informed the specified DR information in the day ahead. The DR operation can be described in Fig. 1 [6]. The DR operation divides a whole day (24 hours, 48 intervals) into two sections; one is before DR event notification (h_{DRS-2}), specified by "$before\ DR$" and the other is after the notification at "h_{DRS-2}" specified by "$After\ DR$". The DR event in the DR market is modeled to happen from "h_{DRS}" to "h_{DRE}" for the simplicity. The total load reduction to the requested DR is measured by difference between the actual electricity consumption after DR request and CBL. Therefore, if end-users know a specified DR event one day before. DR operation of DR resources can be optimized by certain DR event information in day ahead.
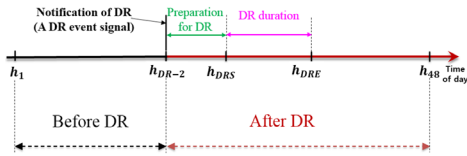

Fig. 1. Time chart DR operation used in the DR market

4. Mathematical Formulation

This section deals with two operation scheduling's such as day-ahead scheduling with temperature forecast error and operation rescheduling on D-day. Day-ahead scheduling W/ forecast temperature error and rescheduling on D-day assume actual temperature has greater difference compared to day-ahead forecast temperature. The main purpose of two operation

scheduling using chiller system and ESS are to minimize daily expected energy cost with maximum DR reward and avoiding penalty threat under thermal comfort constraints and scenarios for uncertain DR events and ambient temperatures.

4.1 Objective function

$$\min \quad \sum_{d=0}^{n_d} \sum_{h=1}^{n_h} p^{(d)} \cdot C_h^{(d)} \tag{1}$$

where d, h, $p^{(d)}$, and $C_h^{(d)}$ are index for DR duration scenarios, index for 30-minute interval in a day, occurrence probability of DR event and the total costs associated with DR events [KRW] respectively. The total costs associated with DR events are represented as follows:

$$C_h^{(d)} = \begin{cases} U_{T,h} \cdot P_{Utility,h}^{(d)} \cdot \dfrac{30}{60} - C_{E,h}^{(d)} & \left(h_{DRS}^{(d)} \le h \le h_{DRE}^{(d)}, d \ne 0\right) \\ U_{T,h} \cdot P_{Utility,h}^{(d)} \cdot \dfrac{30}{60} & (otherwise) \end{cases} \tag{2}$$

where $U_{T,h}$, $P_{Utility,h}^{(d)}$, $C_{E,h}^{(d)}$, $h_{DRS}^{(d)}$, and $h_{DRE}^{(d)}$ are price for electricity in Time Of Use tariff [KRW/kWh], power purchased from the utility [kW], a reward based on load reduced actually [KRW], starting time of DR, and ending time of DR respectively. A reward based on load reduced actually can be expressed in the following equation.

$$C_{E,h}^{(d)} = U_{E,h} \cdot \left(P_{CBL,h} - P_{Utility,h}^{(d)}\right) \cdot \dfrac{30}{60} \tag{3}$$

where $U_{E,h}$ is incentive price for DR contribution at time h [KRW/kWh] and $P_{CBL,h}$ is customer baseline load at time h [kW]

4.2 Demand and supply balancing constraints

The total power purchased from the grid is equal to the sum of demand load and power consumption of chiller system and ESS as follows:

$$P_{Utility,h}^{(d)} = P_{D,h} + P_{cChiller,h}^{(d)} + P_{ESS,h}^{(d)} \tag{4}$$

where $P_{D,h}$, $P^{(d)}_{cChiller,h}$, and $P^{(d)}_{ESS,h}$ are electricity demand excluding chiller system and ESS, power consumed by chiller system, and net charging or discharging power [kW] respectively

4.3 Operation constraints for ESS

Charging or discharging power of ESS and SOC constraints are represented in (5) and (6) respectively.

$$P^{(d)}_{ESS,h} = P^{+(d)}_{ESS,h} - P^{-(d)}_{ESS,h} \tag{5}$$

$$SOC^{(d)}_{h+1} = SOC^{(d)}_h + \frac{30}{60}\left\{\eta \cdot P^{+(d)}_{ESS,h} - \frac{1}{\eta} \cdot P^{-(d)}_{ESS,h}\right\} \tag{6}$$

$$(SOC_1 = SOC_{48})$$

where $P^{+(d)}_{ESS,h}$, $P^{-(d)}_{ESS,h}$, $SOC^{(d)}_h$, and η are charging power of ESS [kW], discharging power of ESS [kW], state of charge, and the total efficiency of ESS (one-way) respectively.

4.4 Characteristics of chiller system

The power consumption of chiller system is simply formulated as the following linear function.

$$P^{(d)}_{cChiller,h} = A \cdot d^{(d)}_{c,h} \cdot \frac{30}{60} + B \tag{7}$$

where A, $d^{(d)}_{c,h}$, and B are power variation of chiller system according to a unit temperature variation [kW/deg-C], hourly temperature variation by chiller system [deg-C/h], and minimum chiller system operation power [kW] respectively.

4.5 Dynamics of indoor temperature

Indoor temperature in a COB is varied by a first order difference equation in (8) and (9). That is, the hourly temperature variation by chiller system is determined based on day-ahead forecasting temperatures under all DR event scenarios. Variation range of indoor temperature in (10) is set based on the thermal comfort of ASHRAE in summer season [7].

$$T^{(d,\ k)}_{iin,h+1} = T^{(d,k)}_{iin,h} + \frac{30}{60} \cdot \left(d^{(d,k)}_{u,h} - d^{(d)}_{c,h}\right) \tag{8}$$

$$d^{(d,k)}_{u,h} = \frac{\left(T^{(k)}_{o,h} - T^{(d,k)}_{iin,h}\right)}{\tau_T} \tag{9}$$

$$T^{\min}_{iin} \leq T^{(d,k)}_{iin,h} \leq T^{\max}_{iin} \tag{10}$$

where k, $T^{(d,k)}_{iin,h}$, $T^{(k)}_{o,h}$, $d^{(d,k)}_{u,h}$, and τ_T are index for day-ahead forecasting temperature scenarios, indoor temperature [deg-C/h], ambient temperature [deg-C/h], hourly temperature variation caused by heat-penetration through the building walls [deg-C/h], and thermal flywheel factor respectively.

Here, the day-ahead forecasting temperature provided by the national weather service in the Korea is used as a medium temperature scenario. And then, a medium temperature scenario with 3% mean absolute percentage errors (MAPE) are also applied in the day-ahead scheduling, called high and low temperature as scenarios.

4.6 DR requirement and CBL constraints

When a DR event happens, End-users should reduce their electricity consumptions as much as 100 [%] reduction of the contracted DR capacity based on upper and lower bound constraints in (11).

$$0.8 \cdot P_{DR} \leq P_{CBL,h} - P^{(d)}_{Utility,h} \leq 1.2 \cdot P_{DR} \tag{11}$$

$$\left(h^{(d)}_{DRS} \leq h \leq h^{(d)}_{DRE}, d \neq 0\right)$$

where P_{DR} is requested load reduction [kW].

4.7 Consistency before DR event notification

The end-user only changes the DR resource (chiller system and ESS) operations after the DR event notification comes; that is, the DR resource operations before the DR notification must be same as follows.

$$P^{(d)}_{cChiller,h} = P^{(5)}_{cChiller,h} \quad \left(h \langle h^{(d)}_{DRS}, d \neq 0\right) \tag{12}$$

$$P^{(d)}_{ESS,h} = P^{(5)}_{ESS,h} \quad \left(h \langle h^{(d)}_{DRS}, d \neq 0\right) \tag{13}$$

4.8 Capacity limit constraints

The capacity constraints for utility company and chiller system are represented in (14) and (15) respectively. The maximum charging or discharging

power of ESS are limited by the maximum ESS power as shown in (16) and (17) respectively. Battery energy stored cannot exceed the maximum storage capacity in (18).

$$0 \leq P_{Utility,h}^{(d)} \leq P_{Utility}^{\max} \tag{14}$$

$$P_{cChiller}^{\min} \leq P_{cChiller,h}^{(d)} \leq P_{cChiller}^{\max} \tag{15}$$

$$P_{ESS,h}^{-(d)} \leq P_{ESS}^{\max} \cdot \mu_h^{(d)} \tag{16}$$

$$P_{ESS,h}^{+(d)} \leq P_{ESS}^{\max} \cdot \left(1 - \mu_h^{(d)}\right) \tag{17}$$

$$SOC^{\min} \leq SOC_h^{(d)} \leq SOC^{\max} \tag{18}$$

where $\mu_h^{(d)}$ is binary variables specifying ESS operation mode (charge = 0 or discharge = 1).

4.9 Rescheduling of DRR operations on the D-day

When the indoor temperature violates and is leaving from the thermal comfortable range, the rescheduling process is activated and DRR operations defined by the day-ahead scheduling is revised based on the updated ambient temperature forecast [8]. The proposed rescheduling process is almost same as the day-ahead scheduling proposed in the previous section, except the targeted time intervals: in the rescheduling process, just focuses on intervals from the current one to end of the D-day.

5. Simulation Results

5.1 Simulation conditions

The proposed DR management algorithm for day-ahead operation scheduling with temperature forecast error is applied to a COB model with 500 [kW] chiller system and 1,000 [kW]/2,000 [kWh] ESS (Lithium-ion battery). Single daily load pattern is assumed for the electricity demand in a COB except ESS and chiller system as shown in Fig. 2. Other assumptions for simulation are almost same as Table 1 Assumed DR event scenarios are same as Table 2. Fig. 3 shows the forecasted ambient temperature profiles for

the day-ahead operation scheduling as scenarios. That is, day-ahead forecast temperature becomes a medium temperature scenario. And then, two temperature scenarios generated by a medium temperature scenario with ± 3% mean absolute percent error (MAPE) was applied to overcome day-ahead forecast error on D-day.

Table 1. Simulation parameters

Parameters		Value
$U_{T,h}$	10:30 ~ 12:00, 13:30 ~ 17:00	293.8 KRW/kWh
	23:00 ~ 9:00	56.2 KRW/kWh
	Otherwise	108.5 KRW/kWh
A, B		290 kW/deg-C, 110 kW
τ_T		11.2
η		80 %
$P_{Utility}^{\max}$		3,000 kW
$SOC^{\min}, SOC^{\max}$		200 kWh, 1800 kWh
$P_{cChiller}^{\min}, P_{cChiller}^{\max}$		139, 500 kW
$T_{iin}^{\min}, T_{iin}^{\max}$		22, 24 deg-C
$U_{E,h}$		550 KRW/kWh
P_{DR}		200 kW

Table 2. Assumed DR event scenarios

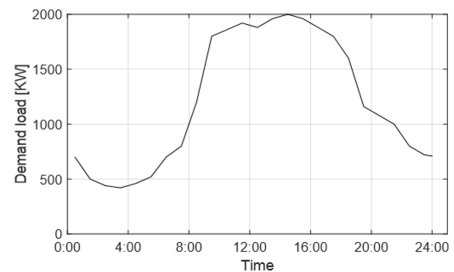| DR scenario	Duration	Requested curtailment	Occurrence probability
1	13:30-15:30	100%	0.1
2	14:00-16:00	100%	0.1
3	14:30-16:30	100%	0.1
4	15:00-17:00	100%	0.1
5	N/A	0%	0.6

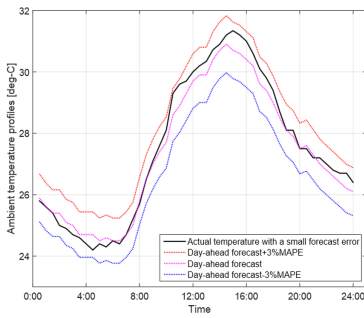Fig. 2. Daily load data of a COB excluding chiller system and ESS

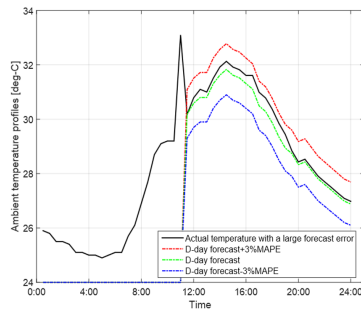**Fig. 3.** Temperature profiles for day-ahead operation scheduling

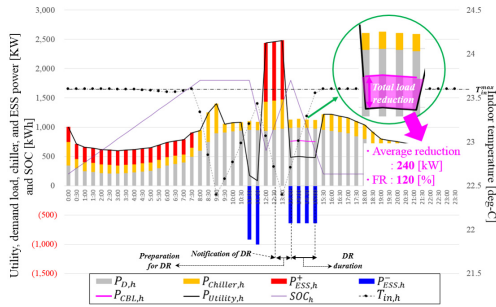**Fig. 4.** Temperature profiles for operation rescheduling

Fig. 5. Obtained optimal operations for day-ahead scheduling (Conventional) d=1 and k=2
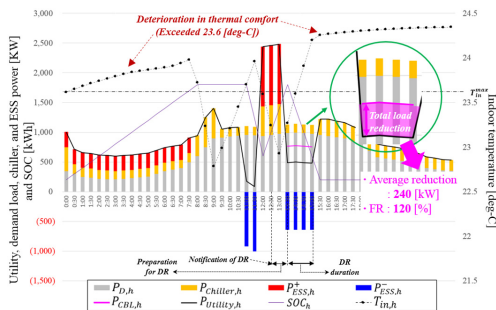

Fig. 6. Obtained optimal operations for day-ahead scheduling (Conventional) d=1 and k=1

The thermal comfort is originally specified as 22.0 - 24.0 [deg-C] by the American Society of Heating, Refrigerating and Air Conditioning Engineers [9]. In this paper, narrower thermal comfort is applied as 22.4 - 23.6 [deg-C] considering 0.4 [deg-C] margins, which is set as maximum possible margins for chiller system operation to be robust the thermal comfort. Other actual temperature with a large forecast error was exceeded the set forecast error range (Actual T2) as shown in Fig. 4. More specifically, the actual ambient temperature on D-day was rapidly increased at 10:30 and then, exceeded the day-ahead forecasting ambient temperature with +3% MAPE at 11:00. The proposed rescheduling process was evaluated with the updated three ambient temperatures specified by "D-day forecast" and "D-day forecast 3% MAPE" from 11:30 on D-day.

5.2 Obtained optimal Day–ahead operation scheduling

We ascertained the validity of the proposed operation scheduling through case studies. Fig. 5 shows simulation results for day-ahead operation scheduling applied with DR scenario 1 (d=1) and a day-ahead temperature forecast (k=2). Obtained optimal operations of electricity demand excluding chiller system and ESS (gray bar), power consumed by chiller system (orange bar), net charging or discharging power (red or blue bar), state of charge (purple solid line), and customer baseline load (pink line), and indoor temperature (black dotted line) were summarized respectively. In this case, day-ahead operation scheduling for chiller system and ESS was optimized for minimal energy cost until 12:30 (before DR happen). When an event DR signal was notified to the DR participant at 12:30, chiller system consumed the maximum power consumption as 500 [kW] for acquiring a DR resource as pre-cooing during preparation for DR (12:30-13:30). ESS was also charged as the maximum power output until SOC is charged up 100% in the same time. Then, chiller

system consumed at 139 [kW] as the minimum power output for DR contribution during the DR duration. Moreover, ESS was concentrated to discharge up to 630 [kW] during the specified DR duration. Total amount of load reduction was calculated that customer baseline load (CBL) minus power purchased from utility company during DR duration. As a result, average load reduction was obtained 240 [kW] as the maximum value constrained maximum fulfillment rate as 120% in (11). Since the cooperation between chiller system as pre-cooling and ESS as discharge affected to make higher DR reward. It was found that resultant indoor temperatures was maintained within thermal comfort range regardless of the DR event.

On the other hand, we applied an actual temperature loci as a day-ahead forecast +3% MAPE (k=1) on D-day and applied to the previous simulation results in Fig. 6. Obtained operation scheduling of chiller system and ESS was same as the previous simulation results as shown in Fig. 5. As you can see, the resultant indoor temperature was exceeded the set thermal comfort range (22.4 [deg-C] - 23.6[deg-C]) from 0:00-7:00 and 14:30-24:00. This is because the forecast error on D-day affected to the day-ahead operation scheduling. Therefore, power consumption of chiller system and ESS should be considered the forecast error on-Day for the constrained thermal comfort range, minimal energy cost, and maximum DR reward.

Fig. 7 shows simulation results for day-ahead operation scheduling by the proposed method. As shown in this Figure, three optimized resultant indoor temperature (red, gray, and blue dotted lines) under the three ambient temperature scenarios specified by "DA forecast" and "DA forecast 3% MAPE" shown in Fig. 3 were represented. The proposed DR operation scheduling using by chiller system and ESS in day-ahead was obtained for the DR event scenario 1 to compare with the simulation results in Fig. 6. In proposed operation scheduling, the operations of chiller system were optimized considering both of TOU tariff and three day-ahead forecast temperature scenarios

before a DR event happened until 12:30. In this period, three resultant indoor temperatures were maintained with the set thermal comfort range. Since amount of power consumption by chiller system was optimized by the three day-ahead forecast temperature scenarios. ESS charge or discharge rate and time interval was optimized for minimal energy cost under TOU tariff until a DR event is notified. When the DR event signal was notified at 12:30, ESS was charged up to 100% of SOC during preparing for DR and discharged for maximum DR reward during the DR duration. Average
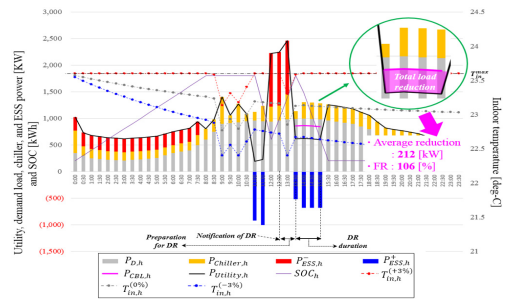

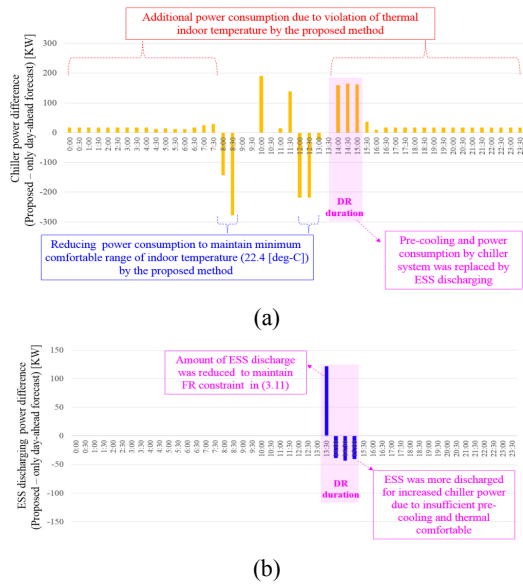Fig. 7. Obtained optimal operations for day-ahead scheduling (Proposed)

(a)

(b)

Fig. 8. Analyses of obtained power consumption by the proposed method (Proposed – Conventional) (a)Chiller power difference (b)ESS discharging difference

load reduction was obtained 212 [kW], in which the value is smaller than the result in Fig. 6 by 28 [kW]. Because chiller system was more consumed to maintain comfortable indoor temperature during 0:00-7:00 and 14:00-23:00, As well as the DR duration as shown in Fig. 8 (a). Meanwhile, power consumed by chiller system was increased during DR duration. This is because Pre-cooling and power consumption by chiller system was replaced by ESS discharging during DR duration as shown in Fig. 8 (b). That is, ESS was more discharged to obtain as possible as maximum DR reward duo to reduced amount of chiller power caused by insufficient pre-cooling and thermal comfortable during DR duration. As a result, the proposed operation scheduling not only can obtain as possible as maximum DR reward by cooperation between chiller system and ESS regardless of DR event, but also can enhance the robustness and effectiveness of the temperature forecast error on D-day

5.2 Obtained optimal Operation rescheduling on D-day

This section concerned with the effectiveness of the development operation rescheduling on D-day itself. The proposed method helps the DR participant to find the point of uncomfortable indoor temperature for the process. Specifically, it aids in maintaining thermal comfort for occupants of buildings by updated ambient temperature forecast on D-day.

On the other hand, when the other actual temperature (Actual T2) is largely different from the forecasted scenarios, the resultant indoor temperature was violated the upper narrower comfort range (23.6 [deg-C]) at 11:00 as shown in Fig. 4. Further, it was over than 24 [deg-C] from 13:00. This would be disadvantaged to DR market participators such as losing work efficiency, decreasing reward for DR, and increasing DR penalty threat.

Therefore, the rescheduling should be activated and the DR schedules should be revised by the proposed method. Fig. 9 shows obtained simulation results

applied with the actual temperature (Actual T2). The operation of chiller system and ESS was not changed before the set comfortable temperature range is exceeded until 11:00. Resultant indoor temperature was increased up 23.61 [deg-C] at 11:00. Therefore, the operation rescheduling was activated and power consumption of chiller system was increased based on the mentioned three temperature scenarios ("D-day forecast" and "D-day forecast 3% MAPE") as shown in Fig. 10. As a result, chiller system was concentrically more consumed for comfortable temperature range from 11:30 ~ 12:30 as shown Fig. 11. Finally, resultant indoor temperature was effectively maintained within the comfortable range. As a result, the anticipated temperature loci can be maintained within the thermal comfort. On the other hand, DR contribution using by chiller system and ESS was stably obtained after rescheduling as shown in Fig. 12.
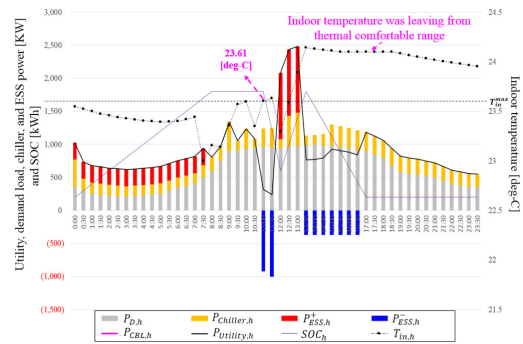

Fig. 9. Obtained optimal operations rescheduling on D-day (Applied with Actual T2)
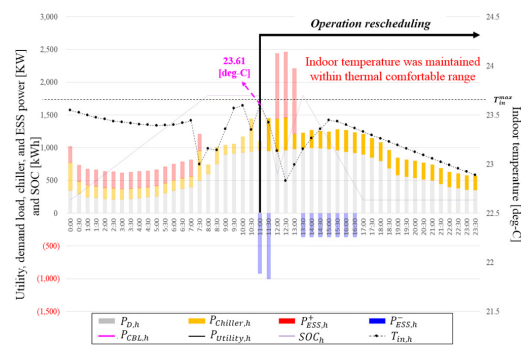

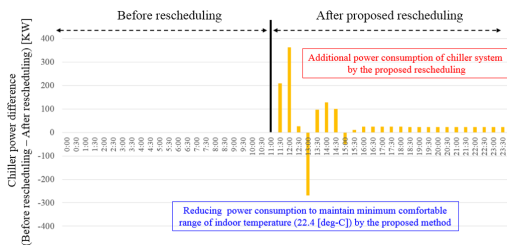**Fig. 10.** Obtained operation rescheduling

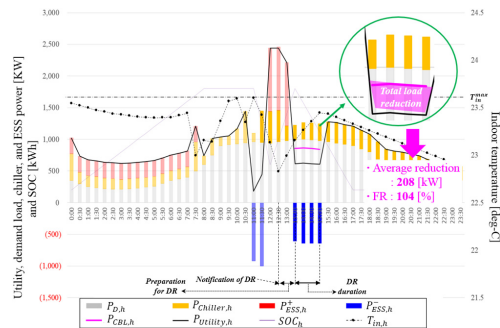Fig. 11. Analysis of rescheduled power consumption of chiller system

Fig. 12. Obtained optimal operation after rescheduling

Average load reduction was 208 [kW]. Insufficient pre-cooling by chiller power was replaced by ESS discharge during DR duration. Therefore, the proposed operation rescheduling can be robust for thermal comfortable indoor temperature and maximum DR reward regardless of DR events.

6. Conclusion

The proposed DR energy management supports additional utilization of chiller system and ESS as a DR resource for the Korean DR market. It proposes an optimal day-ahead operation scheduling whether temperature forecast error or not, and operation rescheduling on D-day for chiller system and ESS in a COB under the DR scheme. Uncertainties in variety DR events applied with specified DR duration and amount of curtailment, and forecast error of ambient temperatures are considered for day-ahead operation scheduling and operation rescheduling on D-day compared with the no temperature forecasting error

method. Simulation results showed that chiller system and ESS were cooperated for under maximum DR profit under DR events and minimum energy cost under TOU tariff. The proposed method not only can make higher DR profit, but also can protect penalty threat. Major advantages of the proposed algorithm are as follows.

- DR request can be met under the uncertainty of temperature.
- Comfort indoor temperature are guaranteed regardless of DR event.
- The proposed day-ahead schedule is robust for the assumed size of forecast error.
- The rescheduling process assures that the indoor temperature can be maintained within the thermal comfort.

References

[1] S. W. Kang, S. H. Chang, H. J. Kim, S. S. Kim, Y. W. Lee, "A Study on Operating Method to Save Energy from the Adsorption Dryer in the Process of Purifying Compressed Air", *Journal of the Society of Korea Industrial and Systems Engineering*, Vol.39, No.3, pp.180-191, 2016.
DOI: https://dx.doi.org/10.11627/jkise.2016.39.3.180

[2] J. H. Han, J. G. Na, C. B. Kim, "Network Analysis of Technology Convergence on Decentralized Energy by Using Patent Information : Focused on Daegu City Area", *Journal of the Society of Korea Industrial and Systems Engineering*, Vol.39, No.3, pp.156-169, 2016.
DOI: https://dx.doi.org/10.11627/jkise.2016.39.3.156

[3] K. Kim, C. Keum, K. S. Chung, "An Evaluation of the Suitability of Data Mining Algorithms for Smart-Home Intelligent-Service Platforms", *Journal of the Society of Korea Industrial and Systems Engineering*, Vol.40, No.2, pp.68-77, 2017.
DOI: https://dx.doi.org/10.11627/jkise.2017.40.2.068

[4] N. S. Kim, "Optimum Power Allocation of Cooperative NOMA Systems based on User Relay", *The Journal of The Institute of Internet, Broadcasting and Communication*, Vol.17, No.5, pp.25-33, 2017.
DOI: https://dx.doi.org/10.7236/JIIBC.2017.17.5.25

[5] N. S. Kim, "Effect of SIC Errors to Cooperative NOMA systems", *The Journal of The Institute of Internet, Broadcasting and Communication*, Vol.17, No.5, pp.35-42, 2017.
DOI: https://dx.doi.org/10.7236/JIIBC.2017.17.5.35

[6] S. J. Oh, "Design of the Smart Application based on IoT", *The Journal of The Institute of Internet,*

Broadcasting and Communication, Vol.17, No.5, pp.151-155, 2017.
DOI: https://dx.doi.org/10.7236/JIIBC.2017.17.5.151

[7] Jonson controls, Demand Response Reference Information. [Internet]. Demand Response in Commercial Buildings, Available From: https://pdfs.semanticscholar.org/presentation/5ae1/0e4c9adab6ba7e152601c8e60543b6676cfd.pdf (accessed Sep., 28, 2007)

[8] R. Walawalkar, S. Fernands, N. Thakur, K. R. Chevva, "Evolution and current status of demand response (DR) in electricity markets: Insights from PJM and NYISO", *ENERGY*, Vol.35, No.4, pp.1553-1560, April 2010.
DOI: https://dx.doi.org/10.1016/j.energy.2009.09.017

[9] J. W. Kim, "A Study on Deterministic Utilization of Facilities for Allocation in the Semiconductor Manufacturing", *Journal of the Society of Korea Industrial and Systems Engineering*, Vol.39, No.1, pp.153-161, 2016.
DOI: https://dx.doi.org/10.11627/jkise.2016.39.1.153

[10] Federal Energy Regulatory Commission (FERC), Demand Response Reference Information. [Internet]. Assessment of Demand Response and Advanced Metering (Staff Report), Available From: http://www.ferc.gov/legal/staff-reports/09-07-demand-response.pdf

(accessed Sep., 28, 2007)

[11] Korea power exchange (KPX), Demand Response Market Reference Information. [Internet]. Demand Response Market Operation Regulation., Available From: http://dr.kmos.kr/main/market_01.htm (accessed Nov., 1, 2014)

[12] J. Son, R. Hara, H. Kita, E. Tanaka, "Energy management considering demand response resource in commercial building with chiller system and energy storage systems", *Proc. of The 2nd IEEE Conference on Power Engineering and Renewable Energy (ICPERE) 2014*, pp.66-69, Dec. 2014
DOI: https://dx.doi.org/10.1109/ICPERE.2014.7067239

[13] J. Son, R. Hara, H. Kita, "Determination of the optimal DR capacity for a commercial building with chiller system and energy storage system", *IEEJ Transactions on Electrical and Electronic Engineering*, Vol.12, No.4 pp.536-545, Jul. 2017.
DOI: https://dx.doi.org/10.1002/tee.22409

[14] S. Taylor, P. Dupont, B. Jones, T. Hartman, M. Hydeman, "Cool Tools Chilled Water Plant Design and Specification Guide", PG&E Cool Tools Report CT-016, May 2000

[15] J. Son, R. Hara, H. Kita, E. Tanaka, "Operation scheduling considering demand response in a commercial building with chiller system and energy storage system", *Proc. of 2015 IEEE PES Asia-Pacific Power and Energy Engineering Conference (APPEEC)*, pp.1-5, Dec. 2015
DOI: https://dx.doi.org/10.1109/APPEEC.2015.7381008

[16] "Thermal Environmental Conditions for Human Occupancy", The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard: ANSI/ASHRAE 55-1992

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