Optimal Scheduling Method of Community Microgrid with Customer-owned Distributed Energy Storage System

Hyung-Chul Jo, Jong-Yul Kim, Gilsung Byeon, and Seul-Ki Kim
Distributed Power System Research Center
Korea Electrotechnology Research Institute
Changwon-si, Republic of Korea
hcjo@keri.re.kr, jykim@keri.re.kr, gsbyeon@keri.re.kr, blksheep@keri.re.kr

***Abstract*— As the penetration of renewable energy resources in power systems increases, high voltage (HV) power systems require solutions that solve the problems regarding supply and demand balance caused by these resources. Community microgrids can provide a viable solution to this problem by providing flexibility service to the HV power system. This study presents an optimal scheduling method of community microgrids with distributed energy storage systems (DESSs) under the circumstance providing flexibility service. Providing the flexibility service is achieved by controlling the power purchased from the external grid and mitigating the variability of the microgrid's net load. DESS is considered as non-controllable DER in this paper. A customer DESS (CDESS) market scenario, based on a price signal market model, is proposed to consider DESS in the microgrid operation. The proposed method is divided into the controllable DER scheduling method, considering the variability of net load, and the CDESS market operation method. Numerical simulations are carried out to demonstrate the effectiveness of the proposed method.**

Keywords*— *Community microgrid, optimal DER scheduling, flexibility, variability of net load, distributed energy storage systems

NOMENCLATURE

$C_{grid}(t)$	Cost of the power purchased from the external power grid at time t.
$C_{LFC}(t)$	Operating cost of large-scale fuel cell (LFC).
$EP(t)$	Electricity price at time t.
$HMP(t)$	Hourly market price.
$P_{grid}(t)$	Power purchased from the power grid at time t.
$P_{LFC}(t)$	LFC generation at time t.
$P_{LESS}(t)$	Power of the LESS charging or discharging.
$P_{DESS}(t)$	Power of the distributed energy storage system (DESS) charging or discharging.
P_{LESS}^{max}	Charging limits of the LESS.
P_{LESS}^{min}	Discharging limits of the LESS.
P_{DESS}^{max}	Charging limits of the DESS.
P_{DESS}^{min}	Discharging limits of the DESS.
P_{LFC}^{min}	Minimum generation limits of LFC.
P_{LFC}^{max}	Maximum generation limits of LFC.
$P_{netload}(t)$	Net load in a community microgrid at time t.
$P_{netload}^{ori}(t)$	Original net load of the community microgrid.
$P_{PV}(t)$	Power supplied by the PV at time t.
$P_{Load}(t)$	Total demand in a community microgrid at time t.
a, b, c	Fuel cost coefficients of LFC.
$SOC_{LESS}(t)$	State of Charge in large-scale energy storage system (LESS) at time t.
SOC_{LESS}^{min}	Minimum state of charge (SOC) of LESS.
SOC_{LESS}^{max}	Maximum SOC of the LESS.
$SOC_{DESS}(t)$	SOC in the DESS.
SOC_{DESS}^{min}	Minimum SOC of DESS.
SOC_{DESS}^{max}	Maximum SOC of the DESS.
Cap_{LESS}	Capacity of LESS.
Cap_{DESS}	Capacity of DESS.
α	Limit for variability of net load in community microgrid.
η_{LESS}	Efficiency of the LESS.
η_{DESS}	Efficiency of the DESS.

I. INTRODUCTION

Power systems have been transitioning from systems based on traditional fossil fuel generators to systems comprising a large amount of renewable energy. Renewable energy resources have become valuable resources for power systems to solve environmental problems. However, many experts have noted that these new energy resources can cause several problems for power system operation, such as duck curve [1], [2] and the increase in flexibility requirements [3]-[5].

For solving these problems in power systems, system operators have typically utilized traditional bulk power generation resources, such as thermal and hydro units. However, traditional methods using the bulk power generation resources cannot solve the duck curve problem caused by oversupply of renewable energy resources. The traditional method also requires high investment costs to install fast ramping units in power systems, to satisfy the increased flexibility requirement imposed by renewable energy.

Due to the limitations of the method using traditional generators, various methods to solve the problems caused by renewable energy have been researched in both large-scale and small-scale approaches. The large-scale approach is characterized by managing the output of renewable energy resources in the high voltage (HV) power system [6]-[9]. In the

978-1-7281-1156-8/19/$31.00 ©2019 IEEE

large-scale method, the amount of curtailed renewable energy will be increased under power system environments, with the increasing penetration of renewable energy resources. The small-scale approach proposes a method using distributed energy resources (DERs), such as demand response resources [10] and energy storage systems (ESSs) [11]. In addition, there are only a handful of papers on controlling a variability of net load in microgrid for renewable energy integration [12]-[14]. Most of these studies focus on scheduling controllable DERs in the microgrid, such as large-scale ESSs and fuel cells (FCs).

However, non-controllable DERs owned by customers, such as small-scale distributed energy storage systems (DESS) for buildings and electric vehicles, can be also included in the community microgrid. Although DESSs are generally considered as an additional load that can cause operational problems in the system, they can function for energy storage as potential available resources [15]. In a community microgrid, if DESSs are considered as available resources, capacity of controllable DERs required for microgrid operation and the investment cost of microgrid can be reduced. Thus, DESS can be an attractive solution for community microgrid that controls the variability of net load.

This study proposes a cost-effective method for operating the community microgrid with large-scale ESSs (LESSs) and large-scale fuel cells (LFCs) as controllable DERs, and DESSs as non-controllable DERs. The method aims to determine the optimal schedule of LESS and LFC considering DESSs, while minimizing their operating cost and mitigating the variability of microgrid's net load. In order to incorporate DESSs in microgrid operation, a customer DESS (CDESS) market model is proposed. The proposed method can be divided into the LESS & LFC scheduling method considering the net load variability and CDESS market operating method, in which the DESS operation schedule is determined. In the LESS & LFC scheduling method, the scheduling problem is formulated as a non-linear programming problem and variability of the net load is formulated as the constraints based on the amount of power exchange with the external power grid. In the CDESS market operation method, a market model is based on the price signal market model [16], where resource owners respond to the published price signal.

This paper is organized as follows. Section II provides the details of the community microgrid and the CDESS market. In Section III, the optimal scheduling method of the community microgrid with DESSs, considering the variability of net load, is proposed. In Section IV, the numerical simulation results are presented to demonstrate the effectiveness of the proposed method. The conclusions are presented in Section V.

II. Community Microgrid and Customer Distributed Energy Storage System Market

A. *Community Microgrid*

A community microgrid is a distribution system for a community consisting of distributed generation resources and ESSs that supply self-generated energy to the microgrid or receive electricity from an external power grid to meet increasing demand. The community microgrid is composed of PV systems, FCs, and ESSs. PV systems have no fuel cost and cannot be controlled by the microgrid operator once they are installed. Owing to the uncertainty and variability of the PV systems, LESS and LFC that can be controlled by the microgrid operator are required to increase the reliability within the microgrid and provide the flexibility service to the external power grid. However, there are many DESSs that cannot be controlled by the operator due to the increased use of DESS, such as the residential and commercial ESSs. Figure 1 shows the overview of the community microgrid.

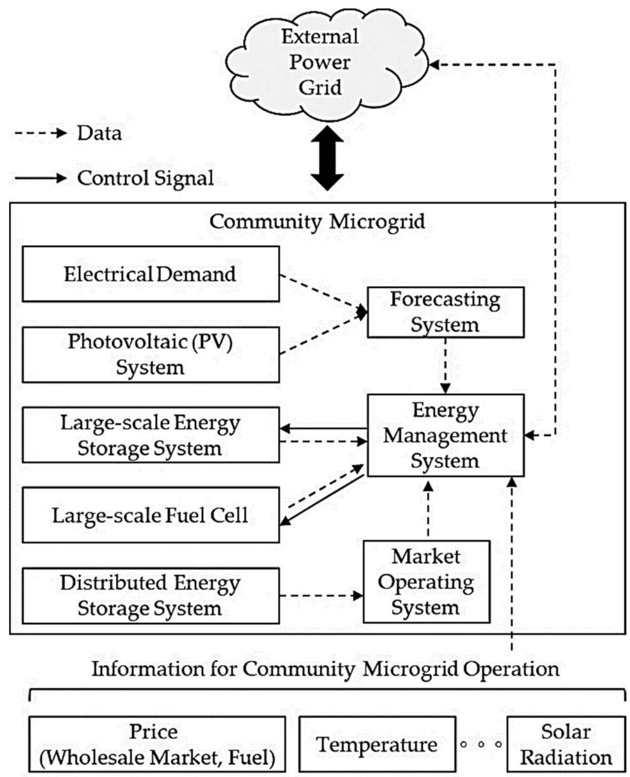

Fig. 1. Overview of community microgrid

The community microgrid operator collects information on the grid operation from DERs and on electricity demand. Using this information, the operator determines the optimal schedule of LESS and LFC to meet the electricity demand. In addition, the community microgrid provides the flexibility service to HV system by controlling $P_{grid}(t)$ and variability of net load based on the signals of HV system. However, the charging/discharging of DESSs can result in an inefficient operation of LESS and LFC in the microgrid and can increase the capacity of LESS and LFC.

B. *Customer distributed energy storage system market model*

A CDESS market model is proposed to utilize DESS for community microgrid operation. The community microgrid operator acts not only as a system operator, but also as a market operator. In the microgrid, most DESSs serve the individual demand and only an excessive amount of charge or discharge is sold to the CDESS market.

The proposed model is designed based on the price signal-based market model [16]. The proposed market allows the DESS to respond to a series of price signals announced by the operator for the microgrid operation. This allows the operator to obtain a certain level of indirect control over the DESS through a variety of market price signals. In this study, the hourly market price is assumed to be set by the market operator. The schedule of the charge/discharge for each DESS is assumed to be determined using the optimization model with the original net load and the hourly market price. The community microgrid operator may purchase DESS charge/discharge in the CDESS market as needed to operate the community microgrid. The process for the CDESS market operation is shown in Figure 2.

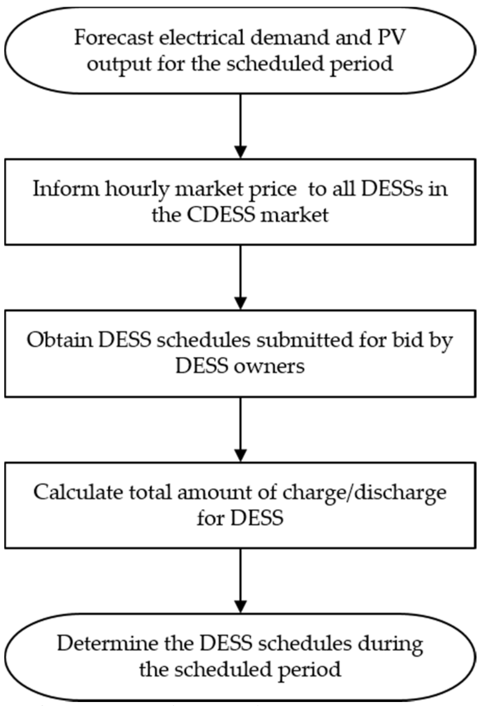

Fig. 2. Process for CDESS market operation

The timeline for the microgrid is shown in Figure 3, where the entire period is divided into the pre-scheduled period and the scheduled period. The day-ahead scheduling for LESS and LFC is performed to provide the power balance to the community microgrid and the flexibility services to the external power grid during the pre-scheduled period. The DESS schedule through the CDESS market is determined prior to the scheduling of LESS and LFC.

The scheduling for community microgrid operation can be repeated every hour with the measured data each hour. However, in this paper, the scheduling method for 24 hours of the following operation day is focused to highlight the method considering DESS in community microgrid.

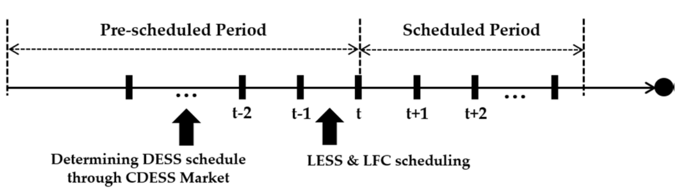

Fig. 3. Timeline for community microgrid operation

III. Optimal Scheduling Method for LESS & LFC Considering Variability of Net load and DESS in Community Microgrid

In this section, an optimal scheduling method for LESS and LFC considering the variability of net load and the DESS in the community microgrid is proposed. The optimization model for the scheduling method is formulated as a non-linear programming problem. Models for the characteristics of ESSs and FCs that have been studied for the home or building energy management [17] are modified and applied to the proposed optimization model. Generalized reduced gradient (GRG) algorithm [18] is used to solve the optimization model in this paper. Details of the proposed method are provided in the following subsections.

A. LESS & LFC scheduling problem considering variability of net load in community microgrid

The objective of the LESS & LFC scheduling problem is to determine the optimal operating schedule of LESS and LFC at each time to minimize the operating cost of the community microgrid, while satisfying the constraints of the characteristics of LESS and LFC, the variability of net load, and power balance.

The objective function for LESS & LFC scheduling problem is expressed as follows:

$$\text{Minimize } \sum_t \left\{C_{grid}(t) + C_{LFC}(t)\right\} \tag{1}$$

$$C_{grid}(t) = P_{grid}(t) * EP(t) \tag{2}$$

$$C_{LFC}(t) = a * P_{LFC}^2(t) + b * P_{LFC}(t) + c \tag{3}$$

This scheduling problem is solved subject to the following constraints.

- State of charge (SOC) dynamics for LESS

$$SOC_{LESS}(t+1) = SOC_{LESS}(t) + \eta_{LESS} * \frac{P_{LESS}(t)}{Cap_{LESS}} \tag{4}$$

- SOC limits of LESS

$$SOC_{LESS}^{min} \le SOC_{LESS}(t) \le SOC_{LESS}^{max} \tag{5}$$

- Charging/discharging limits of LESS

$$P_{LESS}^{min} \le P_{LESS}(t) \le P_{LESS}^{max} \tag{6}$$

- Generation limits of LFC

$$P_{LFC}^{min} \le P_{LFC}(t) \le P_{LFC}^{max} \tag{7}$$

- Power balance constraint of the community microgrid

$$P_{grid}(t) + P_{LFC}(t) = P_{netLoad}(t) + P_{LESS}(t) \tag{8}$$

- Constraint for the variability of net load in the community microgrid

$$|P_{grid}(t) - P_{grid}(t-1)| \le \alpha \tag{9}$$

- Limits of Power purchased from the external grid

$$P_{grid}^{min} \le P_{grid}(t) \le P_{grid}^{max} \tag{10}$$

B. Optimal scheduling algorithm for LESS & LFC considering DESS

This sub-section describes an optimal scheduling algorithm for LESS and LFC considering the DESS in the community microgrid. In Section 2, it was assumed that there is a CDESS market utilizing the DESS for the community microgrid operation. The proposed algorithm is separated into the re-calculation stage of the net load and the optimal scheduling stage for LESS and LFC. In the re-calculation stage, the net load in the microgrid is re-calculated using the DESS operating schedule results obtained from the CDESS market. In the scheduling stage, the schedule of LESS and LFC is determined based on the result of the first stage and the electricity price information. The procedures for the proposed algorithm can be summarized as follows:

Step 1) Use historical data for load and PV generation in the community microgrid and perform day-ahead hourly forecasting of the load and the PV generation.

Step 2) Calculate the original net load at each time based on the results of the day-ahead hourly forecasting using (11).

$$P_{netload}^{ori}(t) = P_{load}(t) - P_{PV}(t) \tag{11}$$

Step 3) Obtain the data for the DESS charge/discharge schedule submitted to the CDESS market. The schedule of DESS is determined using the following optimization model. The objective function of the optimization model is to maximize the revenue of the DESS.

$$Maximize \ \sum_t |P_{DESS}(t)*HMP(t)| \tag{12}$$

$$SOC_{DESS}(t+1) = SOC_{DESS}(t) + \eta_{DESS} * \frac{P_{DESS}(t)}{Cap_{DESS}} \tag{13}$$

$$SOC_{DESS}^{min} \leq SOC_{DESS}(t) \leq SOC_{DESS}^{max} \tag{14}$$

$$P_{DESS}^{min}(t) \leq P_{DESS}(t) \leq P_{DESS}^{max}(t) \tag{15}$$

Step 4) Estimate the total charge/discharge amount $P_{DESS}^{eff}(t)$ of the DESS at each hour to be purchased by community microgrid operator based on the results of Step 3. $P_{DESS}^{eff}(t)$ is calculated from using (16).

$$P_{DESS}^{eff}(t) = \pm min\left(\left|P_{netload}^{ori}(t)\right|, \left|\sum P_{DESS}(t)\right|\right) \tag{16}$$

where $P_{DESS}^{eff}(t)$ is positive if $\sum P_{DESS}(t) > 0$ and negative if $\sum P_{DESS}(t) < 0$.

Step 5) Re-calculate the net load of the community microgrid considering $P_{DESS}^{eff}(t)$. The re-calculated net load $P_{netload}(t)$ is

$$P_{netLoad}(t) = P_{netload}^{ori}(t) + P_{DESS}^{eff}(t) \tag{17}$$

Step 6) Determine the optimal schedule of LESS and LFC to minimize the operating cost of the community microgrid by solving the LESS & LFC scheduling problem.

IV. Numerical Simulation Results

In this section, the proposed method is numerically tested using a community microgrid scenario based on data collected from the installed DERs at the Korea Electrotechnology Research Institute (KERI). The community microgrid consists of LESS, LFC, PVs, and DESS. The parameters of each DER in the community microgrid are listed in Table I. For the numerical simulation, the lithium polymer battery is used as the LESS and α is assumed to be 200kW. Data for average ESS investment cost in Korea is used. In addition, it is assumed that it is not possible to sell electricity to an external power grid.

TABLE I. Parameters of Energy Resources in Community Microgrid

Energy Resource	Parameter	
LESS	Capacity	5MW/23MWh
	Charging limit	5MW
	Discharging limit	-5MW
	Min/Max SOC	20%~90%
LFC	Capacity	1.1MW
	Generation limit	0.11~1.1MW
	Coefficient of $C_{LFC}(t)$	0.106 (a)
		-12.97 (b)
		68,243 (c)
PV	Capacity	10MW
DESS	Total capacity	7MW/14MWh
	Capacity of one unit	700kW/1400kWh
	Min/Max SOC	0~100%

The profiles used in the numerical simulation are shown in Figures 4–6. Figure 4 shows the total demand profile in the community microgrid. The demand profile is created based on the historical demand data of the KERI. Data from the 50 kW PV panels installed at the KERI are used and converted to generate 10 MW PV data. Figure 5 shows the generation profile for PV installed in the community microgrid. The price of power purchased from the external power grid and hourly market prices in the CDESS market are shown in Figure 6. The prices in the external power grid are assumed to be based on the system marginal price obtained from the wholesale market operator.

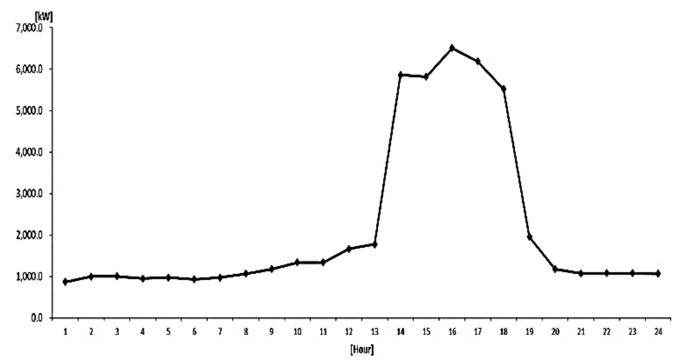

Fig. 4. Total demand profile.

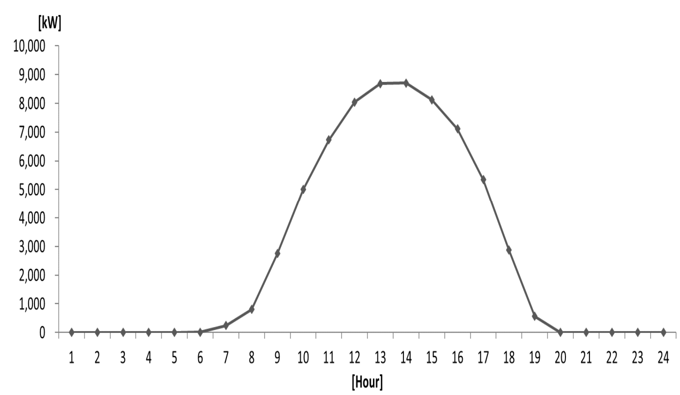

Fig. 5. PV generation profile.

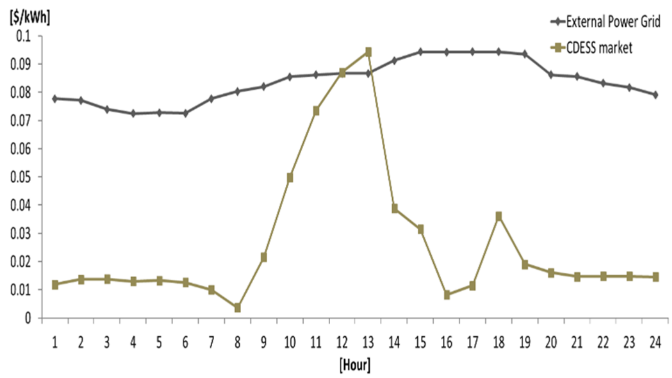

Fig. 6. Hourly prices in external power grid and CDESS market.

The DESS charge/discharge schedule submitted to the CDESS market by each DESS owner is shown in Figure 7. The net load of the community microgrid is demonstrated in Figure 8 where the re-calculated net load means the net load re-calculated using (17) and the submitted DESS schedules. It can be observed from these figures that DESS is charged when the PV generation and CDESS market price are high. And DESS may be discharged even though the market price is low.

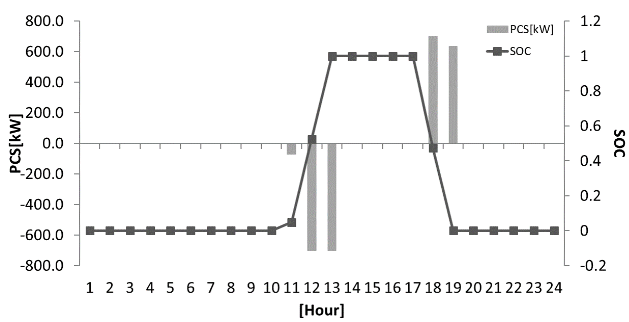

Fig. 7. DESS charge/discharge schedule submitted to CDESS market.

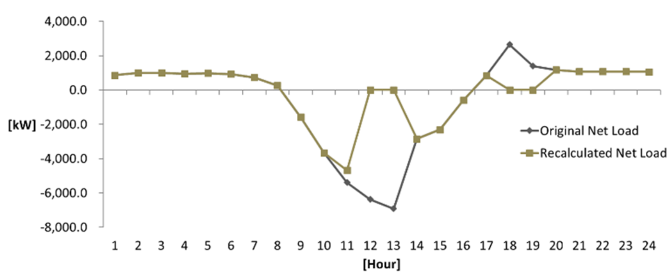

Fig. 8. Net loads of community microgrid.

Figure 9 presents the scheduling results of LESS and LFC in the community microgrid. The operating cost of the community microgrid is approximately $1,800. The results in Figure 9 show that electricity is purchased from the external power grid between 0:00 and 8:00 because the PV generation is almost 0 kW during that time. The charge/discharge of LESS occurs during the early hours (0:00–8:00) to satisfy the constraint on the fluctuations purchased from the external grid. The output of LFC is mostly the generation due to the large amount of PV generation. Before sunrise, the output increases to a point where the operating cost of LFC is lower than the cost for the power bought from the external power grid.

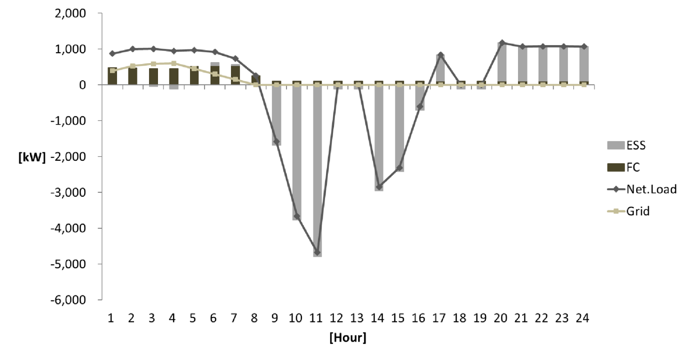

Fig. 9. Scheduling results of LESS & LFC in the community microgrid.

The scheduling results in Figure 9 reflect the variability constraint; the maximum variability is 150 kW. If the variability constraints are not considered in the scheduling problem, the variability of the community microgrid can increase. Figure 10 shows the community microgrid variability for the scheduling results with and without the variability constraints. The maximum variability when the constraints (proposed method) are considered is 41% lower than the other case. In other words, LESS & LFC scheduling by the proposed method considering the variability constraints can reduce the variability of the community microgrid.

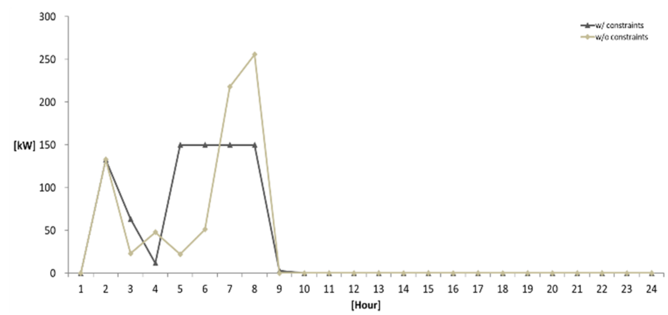

Fig. 10. Community microgrid variability with and without considering variability constraints.

DESS may have an impact on the capacity of LESS and the operating cost for the community microgrid. The cases with and without considering DESS were compared to demonstrate the influence of DESS on the community microgrid. The original net load in Figure 8 shows that in the case without DESS, the capacity of LESS in the microgrid should be increased because it is not possible to sell electricity to an external power grid. Minimum capacity of LESS for the scheduling of community microgrid without considering DESS was 8 MW/44 MWh. The capacity was calculated by an iterative method using various LESS capacity to obtain a feasible solution for scheduling of community microgrid. Inverter ratings and storage capacity increased by 60% and 91%, respectively, compared to the case with considering DESS. The investment cost of LESS increased by 88% (Table II).

TABLE II. COMPARISON OF INVESTMENT COSTS FOR LESS BETWEEN THE CASES WITH AND WITHOUT DESS

Case	***Capacity***	***Investment Cost***
Case w/ DESS	5MW/23MWh	\$15.3m
Case w/o DESS	8MW/44MWh	\$28.8m

Figure 11 presents the scheduling results of LESS and LFC in the case that does not consider the DESS. The operating cost of the community microgrid is almost the same as the case considering the DESS.

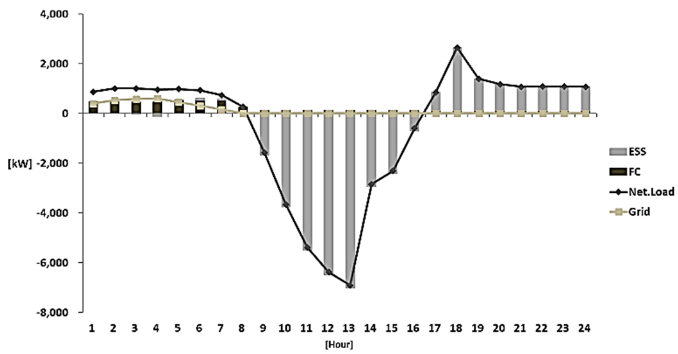

Fig. 11. Scheduling results of LESS and LFC in the community microgrid.

The results show that by considering the DESS in the microgrid scheduling, the investment cost of LESS can be reduced, while the change in the operation cost for LESS and LFC remains small.

V. CONCLUSION AND FUTURE WORK

Community microgrids can become a viable solution for the supply and demand balance problem caused by renewable energy by mitigating its net load variability. This study proposes a cost-effective scheduling method for a community microgrid with a DESS. The proposed scheduling algorithm for the community microgrid operation consists of the LESS & LFC scheduling method considering the variability of net load and the CDESS market operation method for DESS. In the LESS & LFC scheduling problem, the variability of net load is formulated based on the amount of power exchange with the external power grid. In the CDESS market operation method, the market model is based on the price signal market. The results of the numerical simulation showed that the capacity of LESS for community microgrid operation could be reduced.

Further work is required to study the effects of the ESS degradation, the network configuration, the price signal in the CDESS market, forecast errors for PV output and electrical demand, and prosumers in the community microgrid on the performance of the proposed method.

ACKNOWLEDGMENT

This research was supported by Korea Electrotechnology Research Institute (KERI) Primary research program through the National Research Council of Science & Technology(NST) funded by the Ministry of Science and ICT (MSIT) (No. 19-12-N0101-31).

REFERENCES

[1] P. Denholm, M. O'Connell, G. Brinkman, and J. Jorgenson, "Overgeneration from Solar Energy in California: A Field Guide to the Duck Chart," Nat. Renew. Energy Lab., Golden, Co, USA, Tech. Rep. NREL/TP-6A20-65023, Nov. 2015. [Online]. Available: https://www.nrel.gov/docs/fy16osti/65023.pdf

[2] H.O.R. Howlader, M.M. Sediqi, A.M. Ibrahimi, and T. Senjyu, "Optimal Thermal Unit Commitment for Solving Duck Curve Problem by Introducing CSP, PSH and Demand Response," IEEE Access, vol. 6, pp. 4834-4844, Jan. 2018.

[3] M. Huber, D. Dimkova, and T. Hamacher, "Integration of Wind and Solar Power in Europe: Assessment of Flexibility Requirements," Energy, vol. 69, pp. 236-246, May 2014.

[4] E. Lannoye, D. Flynn, and M. O'Malley, "Evaluation of Power System Flexibility," IEEE Trans. Power Syst., vol. 27, no. 2, pp. 922-931, May 2012.

[5] N.E. Koltsaklis, A.S. Dagoumas, and I.P. Panapakidis, "Impact of the Penetration of Renewables on Flexibility Needs," Energ. Policy, vol. 109, pp. 360-369, Oct. 2017.

[6] J. Lee, J. Lee, Y. M. Wi, and S. K. Joo, "Stochastic Wind Curtailment Scheduling for Mitigation of Short-Term Variations in a Power System with High Wind Power and Electric Vehicle," Appl. Sci., vol. 8, no. 9, Sep. 2018, Art. no. 1684.

[7] J. F. Restrepo and F. D. Galiana, "Assessing the Yearly Impact of Wind Power Through a New Hybrid Deterministic/Stochastic Unit Commitment," IEEE Trans. Power Syst., vol. 26, no. 1, pp.401-410, Feb. 2011.

[8] L. Bird, J. Cochran, and X. Wang, "Wind and Solar Energy Curtailment: Experience and Practices in the United States," Nat. Renew. Energy Lab., Golden, Co, USA, Tech. Rep. NREL/TP-6A20-60983, Mar. 2014. [Online]. Available: https://www.nrel.gov/docs/fy14osti/60983.pdf

[9] X. Dui, G. Zhu, and L. Yao, "Two-Stage Optimization of Battery Energy Storage Capacity to Decrease Wind Power Curtailment in Grid-Connected Wind Farms," IEEE Trans. Power Syst., vol. 33, no. 3, pp. 3296-3305, May. 2018.

[10] O. Ma, N. Alkadi, P. Cappers, P. Denholm, J. Dudley, S. Goli, M. Hummon, S. Kiliccote, J. MacDonald, N. Matson, D. Olsen, C. Rose, M. D. Sohn, M. Starke, B. Kirdy, and M. O'Malley, "Demand Response for Ancillary Services," IEEE Trans. Smart Grid, vol. 4, no. 4, pp. 1988-1995, Dec. 2013.

[11] P. Denholm, E. Ela, B. Kirby, and M. Milligan, "The Role of Energy Storage with Renewable Electricity Generation," Nat. Renew. Energy Lab., Golden, Co, USA, Tech. Rep. NREL/TP-6A2-47187, Jan. 2010. [Online]. Available: https://www.nrel.gov/docs/fy10osti/47187.pdf

[12] A. Majzoobi and A. Khodaei, "Application of Microgrids in Addressing Distribution Network Net-Load Ramping," in Proc. IEEE Power Eng. Soc. Innovative Smart Grid Technol. Conf., Minneapolis, MN, USA, Sep. 2016, p. 1-5.

[13] A. Majzoobi and A. Khodaei, "Application of Microgrids in Supporting Distribution Grid Flexibility," IEEE Trans. Power Syst., vol. 32, no. 5, pp. 3660-3669, Sep. 2017.

[14] J. Zhou, J. Zhang, X. Cai, G. Shi, J. Wang, and J. Zang, "Design and Analysis of Flexible Multi-Microgrid Interconnection Scheme for Mitigating Power Fluctuation and Optimizing Storage Capacity," Energies, vol. 12, no. 11, June 2019, Art. No. 2132.

[15] F. P. Sioshansi, "Electric Vehicles: New Problem or Distributed Energy Esset?" in Distributed Generation and its Implications for the Utility Industry, Academic Press, 2014, ch. 17, pp. 335-355.

[16] S. You, C. Træholt, and B. Poulsen, "A Market-Based Virtual Power Plant," In Proceedings of 2009 Int. Conf. Clean Electrical Power, Capri, Italy, June 9-11, 2009.

[17] H. C. Jo, S. Kim, and S. K. Joo, "Smart Heating and Air Conditioning Scheduling Method Incorporating Customer Convenience for Home Energy Management System," IEEE Trans. Consum. Electron., vol. 59, no. 2, pp. 316-322, May 2013.

[18] L. S. Lasdon, R. L. Fox, and M. W. Ratner, "Nonlinear Optimization Using the Generalized Reduced Gradient Method," RAIRO-Rech. Oper., vol. 8, pp.73-103, 1974.