Optimal Scheduling for a Zero Net Energy Community Microgrid With Customer-Owned Energy Storage Systems

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Abstract—With the increasing use of renewable energy resources in power systems, it is necessary to overcome the limitations of these resources in terms of the supply and demand balance in high-voltage power systems. A viable solution is employing zero net energy community microgrids, which can manage the demand locally and minimize the impact to the power grid. To this end, this paper proposes an optimal scheduling method for a zero net energy community microgrid with customer-owned energy storage systems (CES). It is assumed that the microgrid operator operates in the CES market based on a bilateral contract. The CES aggregators constitute the CES and participate in the market. The aggregated CES (ACES) is considered as a single energy storage system in the proposed scheduling method. Numerical examples are presented to demonstrate the effectiveness of the proposed method.

Index Terms—Community microgrid, optimal scheduling, zero net energy, customer-owned energy storage systems.

NOMENCLATURE

| Variable | Description |
|----------|-------------|
| BAT      | Battery     |
| DER      | Distributed energy resource |
| ESS      | Energy storage system |
| EV       | Electric vehicle |
| CES      | Customer-owned ESS |
| ACES     | Aggregated CES |
| FC       | Fuel cell |
| HV       | High-voltage power system |
| HVAC     | Heating, ventilation, and air-conditioning |
| LESS     | MG operator-owned large-scale ESS |
| LFC      | MG operator-owned large-scale fuel cell |
| PCS      | Power conversion system |
| PV       | Photovoltaic system |
| SOC      | State of charge |
| AP       | Daily available time for microgrid operator to use the ACES (in hours) |
| BP\textsubscript{y} | Breakpoint of interval \( y \) |
| \( C\text{ESS}(t) \) | Cost of charging/discharging loss of LESS and ACES at time \( t \) (in $) |
| \( C\text{fixed,1d} \) | Daily fixed cost paid to CES aggregator by microgrid operator in CES market (in $) |
| \( C\text{grid}(t) \) | Cost of power purchased from external power grid at time \( t \) (in $) |
| \( C\text{LFC}(t) \) | Operating Cost of LFC at time \( t \) (in $) |
| \( Cap\text{BAT,ACES} \) | Battery capacity in ACES (in kWh) |
| \( Cap\text{BAT,CES} \) | Battery capacity in CES (in kWh) |
| \( Cap\text{PCS,ACES} \) | PCS capacity in ACES (in kWh) |
| \( Cap\text{LESS} \) | Battery capacity in LESS (in kWh) |
| CRF      | Capacity recovery factor |
| \( EP(t) \) | Electricity price at time \( t \) |
| \( IC\text{BAT} \) | Investment costs per unit of BAT in ACES (in $/kW) |
| \( IC\text{PCS} \) | Investment costs per unit of PCS in ACES (in $/kWh) |
| \( P\text{ACES}(t) \) | Charging/discharging power of ACES at time \( t \) (in kW) |
| \( P\text{ACES,cha}(t) \) | Charging power of ACES at time \( t \) (in kW) |
| \( P\text{ACES,dis}(t) \) | Discharging power of ACES at time \( t \) (in kW) |
| \( P\text{grid}(t) \) | Power purchased from external power grid at time \( t \) (in kW) |
| \( P\text{LESS}(t) \) | Charging/discharging power of LESS at time \( t \) (in kW) |
| \( P\text{max,LESS} \) | Charging PCS limit of LESS (in kW) |
| \( P\text{min,LESS} \) | Discharging PCS limit of LESS (in kW) |
| \( P\text{LFC}(t) \) | LFC generation at time \( t \) (in kW) |
| \( P\text{max,LFC} \) | Minimum LFC generation limit (in kW) |
| \( P\text{max,LESS} \) | Maximum LFC generation limit (in kW) |
| \( P\text{Load}(t) \) | Load in community microgrid at time \( t \) (in kW) |
| \( P\text{PV}(t) \) | Generation of PV system at time \( t \) (in kW) |
| \( PCS\text{y} \) | Maximum output of ACES at interval \( y \) (in kW) |
| \( SOC\text{ACES}(t) \) | SOC of ACES at time \( t \) |
SOC_{min}^{ACES} \quad \text{Minimum SOC of ACES}
SOC_{max}^{ACES} \quad \text{Maximum SOC of ACES}
SOC^{LESS}(t) \quad \text{SOC of LESS at time } t
SOC_{min}^{LESS} \quad \text{Minimum SOC of LESS}
SOC_{max}^{LESS} \quad \text{Maximum SOC of LESS}
Z_{ACES,cha}(t) \quad \text{Binary variable for charging state of ACES at time } t
Z_{ACES,dis}(t) \quad \text{Binary variable for discharging state of ACES at time } t
f(SOC_{ACES}(t)) \quad \text{Piecewise linear function for maximum PCS output considering SOC state of ACES at time } t \text{ (in kW)}
g(SOC_{ACES}(t)) \quad \text{Function that checks whether } SOC_{ACES}(t)\text{ at time } t \text{ belongs to interval } y \text{ (1 or 0)}
a, b, c \quad \text{Fuel cost coefficients of LFC}
n \quad \text{Number of years to be compensated by CES market, as determined by bilateral agreement}
r \quad \text{Interest rate}
w \quad \text{Weight coefficient for cost that constitutes the objective function in the microgrid operation scheduling problem}
y \quad \text{Interval for partitioning SOC range of ACES}
\varepsilon \quad \text{Tolerance of constraint for total charging amount of ACES}
\eta^{ACES} \quad \text{Efficiency of ACES}
\eta^{ACES} \quad \text{Efficiency of CES}
\eta^{LESS} \quad \text{Efficiency of LESS}

I. INTRODUCTION

In recent years, power systems have been transitioning from systems based on traditional fossil fuel generators to those involving renewable energy. In particular, the application of renewable energy resources in power systems is highly desirable to solve environmental problems. However, many experts have noted that such energy resources can lead to several problems in the operation of power systems, such as the occurrence of the duck curve [1] and the increase in flexibility requirements [2], [3]. To address these problems, system operators have typically utilized traditional bulk power generation resources, such as thermal and hydro units. However, in such approaches, high investment costs are required to solve the problems caused by the variation in renewable energy.

To overcome the limitations of methods employing traditional generators, several researchers have attempted to solve the problems caused by renewable energy in both large-scale and small-scale domains. The large-scale approach is characterized by the management of the output of renewable energy resources in HV power systems [4]–[6]. However, the amount of curtailed renewable energy is expected to increase with the more widespread use of renewable energy resources. In the small-scale approach, DERs such as demand response resources [7] and ESSs [8] are employed. In addition, the use of a zero net energy microgrid has been recommended to address the abovementioned problems, as such a grid can locally manage the demands and minimize the impact to the power grid [9], [10].

Installation of LESS and LFC is necessary for zero net energy community microgrid operation. In addition, CESs have been installed in the community to realize electricity cost saving and emergency operation for the owner. From the microgrid operator’s point of view, utilizing CESs in the microgrid operation obviates the need to increase the capacity of the microgrid operator-owned ESS, thereby reducing the investment cost for LESS. Therefore, CESs can be a valuable resource for the microgrid operators in a zero net energy community.

Several studies have been conducted on the optimal DER scheduling method or DER aggregation [11]–[17]. A day-ahead scheduling method for DERs was proposed to generate a look-up table that determines an optimal schedule at each time interval [11]. A scheduling method for building energy supply was proposed in [12]. A scheduling method for various DERs, such as ESS, FC, and HVAC system, was introduced in [13] to reduce the energy cost. An optimal operation for multiple ESSs in a microgrid under time-based pricing was introduced in [14]. A DER scheduling method for a community microgrid with many CESs was proposed based on the bidding-based CES market in [15]. The existing studies aggregating DERs have been mainly conducted on EVs. In [16], multiple individual EVs were aggregated into one virtual EV with accumulated battery capacity. In [17], EVs were aggregated depending on the charging station system framework. Many of these studies for aggregating multiple ESSs presuppose that the CESs have the same C-rate.

This paper is an extension of a preliminary work [11]. In this paper, CESs with different C-rates are considered in the community microgrid scheduling problem. The characteristics of CESs with different C-rates generally cause the CESs to be considered individually in the scheduling problem. When considering the CES models individually, microgrid operators have the burden of directly controlling several CESs. In addition, when the CESs are aggregated without considering the C-rate, a specific CES is charged (or discharged) first, allowing the microgrid operators to unintentionally command unrealistic charge and discharge outputs. For example, if 3 kW/6 kWh CES1 and 1 kW/4 kWh CES2 are aggregated as 4 kW/10 kWh, the operator may issue a command to charge 4 kW for 2.5 h. However, this is an impossible command because CES1 is fully charged in 2 h. The problem may be solved by aggregating the CESs such that the C-rates are unified to a lower value (e.g., 3 kW/6 kWh → 1.5 kW/6 kWh; PCS 1.5 kW is not used). However, in this case, the characteristics of the CESs cannot be fully utilized in the microgrid operation.

To further explore this aspect, in this work, an optimal scheduling method for the zero net energy of a community microgrid involving the aggregation of CESs was developed with the objective of determining the optimal schedule of ESSs, FCs, and ACESs while minimizing the total operating cost and maintaining a zero energy state at the connection point to an HV power system. To incorporate the CESs with various C-rates in the scheduling problem, a CES market model based on bilateral contract and ACES model using the piecewise linear method were developed. In particular, it was assumed that the ACES can be used as a single ESS unit, according to the contract.
The remaining paper is organized as follows. Section II describes the community microgrid and the CES market. Section III elaborates upon the ACES model and optimal scheduling method of the community microgrid with CESs to realize a zero net energy state. Section IV presents the numerical example to demonstrate the effectiveness of the proposed method. The conclusions are presented in Section V.

II. ZERO NET ENERGY COMMUNITY MICROGRIDS AND CES MARKET

A. Zero Net Energy Community Microgrid

A zero net energy community microgrid is a distribution system for a community, which offsets all of its energy use from the distributed generation resources and ESSs available within the environment established for the community. Only when the power balance is not met does the microgrid receive electricity from an external power grid to meet the additional demand.

The zero net energy community microgrid does not require the PV systems, FCs, and ESSs to have a large capacity. In particular, PV systems do not have any fuel cost but cannot be controlled by the microgrid operator once they are installed. To address the uncertainty and variability of the PV systems, LESS and LFCs, which can be controlled by the microgrid operator, are required to increase the reliability within the microgrid and minimize the impact of the microgrid on the HV power system. However, several CESs cannot be controlled by the operator owing to increased use, such as residential and commercial ESSs. Fig. 1 shows the overview of the community microgrid.

The community microgrid operator collects the information regarding the microgrid operation from the DERs, along with the information regarding the electricity demand. Using this information, the operator determines the optimal schedule of the ESSs and FCs to meet the electricity demand. However, the charging/discharging of the CESs that cannot be controlled by the operator can lead to the increased capacity of the ESSs and FCs in the microgrid and their inefficient operation.

B. CES Market Model

In this paper, the ESS, which is generally in a standby state, such as the ESS resource replacing the emergency generator in buildings, is considered the CES in the community microgrid. Thus, it is assumed that the time of availability and capacity of the CESs are fixed.

ACES market model is developed to incorporate CESs in the community microgrid operation. It is assumed that the microgrid operator runs the CES market based on a bilateral contract. The CES aggregators actively correspond with the microgrid operator and the customers. All the customers with a CES can participate in the CES market via the CES aggregators in a hierarchical framework, as shown in Fig. 2.

The CES market is designed to ensure a sufficiently stable CES capacity by ensuring that the microgrid operator pays a certain payment to freely use the remaining capacity of the CES. It is assumed that a bilateral agreement exists between the microgrid operator and the CES aggregator through the CES market, for the microgrid operator to freely use the ACES for one year. Furthermore, the microgrid operator pays the fixed cost stated in the contract considering the customer’s investment cost for the remaining capacity of the CES. This contract allows the customer to earn a fixed income and the aggregator to receive a fee. The minimum daily fixed cost \( C_{\text{fixed},1d} \) paid by...
the microgrid operator is calculated with the following equation using CRF [18].

\[
C_{\text{fixed},1d} = AP \times CRF \times \frac{\text{Cap}_{\text{PCS,ACES}} \times IC_{\text{PCS}} + \text{Cap}_{\text{BAT,ACES}} \times IC_{\text{BAT}}}{8760}
\]

\[
CRF = \frac{r(1 + r)^n}{(1 + r)^n - 1}
\]

Because the proposed CES market is based on a bilateral contract, the aggregator and microgrid operator will be able to reach an agreement at or above \( C_{\text{fixed},1d} \).

Through this agreement, the microgrid operator prepares virtual resources (ACES in this paper), which are modeled as the aggregation of CESs, and uses them for the microgrid operation. This allows the operator to reduce the investment in the LESS, which must be installed directly to realize the microgrid operation.

Individual CESs are directly controlled by the CES aggregator, considering the set point for the ACES decided by the microgrid operator. However, this paper focuses on the method to utilize ACES from the perspective of the microgrid operator.

III. MIP-BASED ACES MODEL AND OPTIMAL SCHEDULING MODEL FOR ZERO NET ENERGY COMMUNITY MICROGRID

This section describes the proposed ACES model and optimal scheduling model for a zero net energy community microgrid.

A. ACES Model

The proposed ACES model is based on models to determine the characteristics of the ESSs installed for home or building energy management [13]. In general, the C-rates of the CESs included in the ACES are rarely the same. Therefore, for the operator to efficiently use the ACES, it is necessary for the coordinator to consider the C-rate of the CES in the energy management problem. In a traditional ESS model [13], the maximum PCS output is fixed in the constraint for maximum charge and discharge; therefore, it is difficult to consider the C-rate of the CES. The proposed model is designed to consider the C-rate of the CESs by changing the charged/discharged power of the ACES, depending on the SOC.

The proposed ACES model can be formulated as follows:

1) **BAT capacity and efficiency of the ACES**

\[
\text{Cap}_{\text{BAT,ACES}} = \sum \text{Cap}_{\text{BAT,CES}}
\]

\[
\eta_{\text{ACES}} = \frac{\sum \eta_{\text{CES}} \times \text{Cap}_{\text{BAT,CES}}}{\text{Cap}_{\text{BAT,ACES}}}
\]

2) **SOC dynamics for the ACES:** If the ACES is charged,

\[
\text{SOC}_{\text{ACES}}(t + 1) = \text{SOC}_{\text{ACES}}(t) - \frac{P_{\text{ACES,cha}}(t)}{\eta_{\text{ACES}} \times \text{Cap}_{\text{BAT,ACES}}}
\]

3) **Charging and discharging state of the ACES**

\[
Z_{\text{ACES,cha}}(t) + Z_{\text{ACES,dis}}(t) \leq 1
\]

4) **Maximum charge and discharge limitations of the ACES:**

The proposed model for the maximum charge and discharge limitation of the ACES, as obtained using the piecewise linear function, is shown in Fig. 3.
Specifically,

\[ -f(SOC_{ACES}(t-1)) \cdot Z_{ACES,cha}(t) \leq P_{ACES}(t) \]  
\[ P_{ACES}(t) \leq f(SOC_{ACES}(t-1)) \cdot Z_{ACES,dis}(t) \]  
\[ f(SOC_{ACES}(t-1)) = \max(PCS_y \cdot g(y, SOC_{ACES}(t-1))) \]  
\[ g(y, SOC_{ACES}(t-1)) = \begin{cases} 
1, & \text{if } SOC_{ACES}(t-1) \in [BP_y - 1, BP_y] \\
0, & \text{otherwise} 
\end{cases} \] 

The proposed ACES model can enable the microgrid operator to use the ESSs more efficiently by incorporating constraints in an optimal scheduling problem of the community microgrid.

**B. MIP-Based Optimal Scheduling Method**

This subsection describes an optimal scheduling algorithm for a zero net energy community microgrid with controllable LESS, ACES, and LFCs. As mentioned in Section II, it is assumed that the community microgrid can determine the availability of the ACES through the CES market.

The objective of the optimal scheduling problem is to determine the optimal operating schedule of the LESS, LFCs, and ACES at each instant to minimize the operating cost of the community microgrid, while satisfying the constraints for the characteristics of the proposed ACES model. The scheduling is executed every 15 min to generate the charging/discharging schedules of the ESSs and generation schedules of the FCs for the remaining time of an operation day. The time resolution for the scheduling problem is 15 min.

The objective function for the scheduling problem can be expressed as follows:

\[ \text{Minimize} \sum_{t} \{ w_1 \cdot C_{grid}(t) + w_2 \cdot C_{LFC}(t) + w_3 \cdot C_{ESS}(t) \} \]  
\[ C_{grid}(t) = P_{grid}(t) \cdot EP(t) \]  
\[ C_{LFC}(t) = a \cdot P_{LFC}^2(t) + b \cdot P_{LFC}(t) + c \]  
\[ C_{ESS}(t) = EP(t) \cdot \{(1 - \eta_{ACES}) \cdot P_{ACES}(t) + (1 - \eta_{LESS}) \cdot P_{LESS}(t) \} \]

The values of \( w_1, w_2, \) and \( w_3 \) are usually 1 in this paper. However, it is also assumed that the value of \( w \) can be arbitrarily adjusted by the microgrid operator in many cases. For example, if the operating cost per unit of the FC is greater than the price of electricity \( EP(t) \), the value of \( w_2 \) may be lower than 1 for zero net energy operation of the microgrid.

The piecewise linear approximation method [19] is used to transform the quadratic formulation of \( C_{LFC}(t) \) to a linear formulation.

This scheduling problem is solved subject to the following constraints.

1) **SOC dynamics for the LESS**

\[ \text{SOC}_{LESS}(t + 1) = \text{SOC}_{LESS}(t) + \eta_{LESS} \cdot \frac{P_{LESS}(t)}{\text{Cap}_{LESS}} \]

2) **SOC limits of the LESS**

\[ \text{SOC}_{min} \leq \text{SOC}_{LESS}(t) \leq \text{SOC}_{max} \]

3) **Charging/discharging limits of the LESS**

\[ P_{min} \leq P_{ACES}(t) \leq P_{max} \]

4) **Generation limits of the LFCs**

\[ P_{min} \leq P_{LFC}(t) \leq P_{max} \]

5) **Power balance of the community microgrid**

\[ P_{grid}(t) + P_{LFC}(t) + P_{PV}(t) = P_{Load}(t) + P_{LESS}(t) + P_{ACES}(t) \]

6) **Constraint for the total charging amount of the ACES**

\[ \sum_{t} P_{ACES,cha}(i, t) + \sum_{t} P_{ACES,cha}(j, t) \leq \varepsilon, \forall i, j \]

The aforementioned ACES model, expressed in (3)–(13), can be considered as the set of constraints for the optimal scheduling problem for a community microgrid. In particular, the formulated optimization problem is a mixed integer linear problem, which is solved using the branch-and-bound algorithm [20].

**IV. NUMERICAL EXAMPLE**

The proposed method was numerically tested by considering a community microgrid scenario based on the historical generation data collected from the installed DERs at the Korea Electrotechnology Research Institute (KERI). In the considered case, the community microgrid consists of LESS, LFCs, PVs, and CESs. It is assumed that the aggregator and microgrid operator reach an agreement at \( C_{fixed1, d} \). The parameters of each DER in the community microgrid are listed in Table I. Lithium polymer batteries are used as the LESS. In addition, it is assumed that electricity cannot be sold to an external power grid. Consequently, it is assumed that a high-capacity ESS is required to prevent the power flow from the zero net energy community microgrid with a large number of DERs to the main grid. In addition, the investment costs for PCS and BAT in ACES and LESS are respectively assumed to be 192 $/kW and 333 $/kWh.

The profiles used in the numerical example are shown in Figs. 4–6. The test was conducted on a weekday in fall (2019/10/16). Fig. 4 shows the total demand profile in the community microgrid, created based on the historical demand data of the KERI. Specifically, data from the 50 kW PV panels installed at the KERI were converted to generate data for the
TABLE I
PARAMETERS OF THE DISTRIBUTED ENERGY RESOURCES (DERs) IN THE MICROGRID

| DER      | Parameters   |
|----------|--------------|
| LESS     | Capacity 4 MW/15 MWh |
|          | Charging Limit 4 MW |
|          | Discharging Limit -4 MW |
|          | Efficiency 95% |
|          | Min/Max SOC 20–90% |
| LFC      | Capacity 6.5 MW |
|          | Generation Limit 0.65–6.5 MW |
|          | Coefficient of $C_{tec}(t)$ 0.0179 (a) |
|          | 12.92 (b) |
|          | 403.171 (c) |
| PV       | Capacity 17.5 MW |
|          | Number of ACES 2 |
|          | Capacity of each ACES 2 MW/4 MWh |
| ACES     | Available time 10–19 h |
|          | Efficiency 95% |
|          | Min/Max SOC 0–100% |
|          | CRF 0.1232 (r = 0.04, n = 10) |

Fig. 4. Total demand profile of the community microgrid.

17.5 MW PV. Fig. 5 shows the generation profile for the PV installed in the community microgrid. The costs of the power purchased from the external power grid are shown in Fig. 6. The prices in the external power grid were assumed to be based on the system marginal price obtained from the wholesale market operator.

It was assumed that each ACES consists of two CESs, the parameters of which are listed in Table II.

Fig. 7 shows the maximum charge and discharge limits of each ACES considered in the numerical example.

Fig. 8 shows the optimal scheduling results for the DERs including the ACESs in the community microgrid. The operating cost of the community microgrid is approximately $54,104. No power is purchased from the external power grid, and the operating cost is a result of the power generation of the FCs. It is noted that the LFC generation occurs at the near rated power between 0:00 and 8:00 because the PV generation is nearly 0 kW during that time. When the PV generates electrical power, the output of the LFCs corresponds mostly to the minimum

TABLE II
PARAMETERS OF THE CESs IN THE ACES

| CES       | Parameters   |
|-----------|--------------|
| CES1      | Capacity 0.8 MW/2.86 MWh |
| (used for ACES1) | Charging Limit 0.8 MW |
|          | Discharging Limit -0.8 MW |
|          | Min/Max SOC 20–90% |
| CES2      | Capacity 1.2 MW/2.86 MWh |
| (used for ACES1) | Charging Limit 1.2 MW |
|          | Discharging Limit -1.2 MW |
|          | Min/Max SOC 20–90% |
| CES3      | Capacity 0.6 MW/2.86 MWh |
| (used for ACES2) | Charging Limit 0.6 MW |
|          | Discharging Limit -0.6 MW |
|          | Min/Max SOC 20–90% |
| CES4      | Capacity 1.4 MW/2.86 MWh |
| (used for ACES2) | Charging Limit 1.4 MW |
|          | Discharging Limit -1.4 MW |
|          | Min/Max SOC 20–90% |

Fig. 5. PV generation profile.

Fig. 6. Hourly prices pertaining to the external power grid.
generation owing to the large amount of PV generation. After sunset, the output increases to a point at which the operating cost of the LFCs is lower than the cost of the power bought from the external power grid. The charging/discharging of the LESS occurs after the early hours (0:00–8:00) to satisfy the power balance of the microgrid.

The ACES charging/discharging schedules are shown in Fig. 9. It can be observed that the SOC of ACES1 and ACES2 increases to 100%, and later reduces to 0%, as it is futile to retain stored power after the time of availability of the ACESs is elapsed. In addition, the PCS output limit and the fact that both the ACESs in the figure are charged to nearly 100% confirm that the proposed ACES model and the constraint for the total charging amount of the ACES are applied together.

If the proposed ACES model is not considered in the optimal scheduling problem, ACES1 may be required to charge more than 0.8 MW at an SOC of 83%. In this case, assuming that the charge is evenly distributed to CES1 and CES2, taking into account the PCS capacity, CES2 can be fully charged at an SOC of 83% of ACES1, making it impossible to physically charge ACES1 more than 0.8 MW. The results indicate that such a case does not occur when the proposed ACES model is considered.

Furthermore, the ACES may influence the capacity of the LESS for a zero net energy community microgrid. In the example, when the ACES is not used for microgrid operation through the CES market, the LESS with a capacity of 8 MW/27 MWh is required to realize the zero net energy operation. Fig. 10 presents the scheduling results of the DERs in the case in which the 8 MW/27 MWh LESS is installed. The operating cost of the community microgrid is almost the same as that in the case when the ACES is incorporated.

In the aforementioned example, the ACES generates $435 per day on the CES market. However, changes in the number of ACES may affect ACES revenue. To examine the influence of the number of the ACES on the revenue of the ACES, further case studies were conducted for different numbers of ACESs. Table III shows the change in ACES revenue with the number of ACESs in microgrid. It can be observed from the results shown in Table III that total ACES revenue is changed by $217.5/day per number of ACES. However, individual ACES revenue is same in all cases, because the CES market is based on a bilateral contract with a fixed payment.
In addition, the minimum LESS capacity required for zero net energy operation of microgrid is expected to limit total ACES revenue at a certain level.

These results indicate that the proposed method can be effectively used to ensure the efficient operation of a community microgrid when employing CESs.

V. CONCLUSION

CESs can be used by consumers in a community microgrid to replace emergency generators or to reduce the consumer electricity costs. In addition, they can be utilized in microgrid operation to reduce the investment made by the microgrid operators in the LESS. To facilitate the application of CESs in the microgrid operation, this paper proposes an optimal scheduling method for a zero energy community microgrid involving CESs and several PV systems. To consider the CESs in the scheduling problem, a CES market model and ACES model are developed. The CES market model is proposed based on a bilateral contract for fixed payments. The proposed ACES model is designed to change the charged/discharged power of the ACES depending on the SOC. The numerical results show that the proposed method can reduce the LESS capacity by enabling the consideration of the CES in the microgrid operation.

Further work is required for developing a real-time operation method and improving the proposed ACES model to consider the detailed characteristics of customers.

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\begin{table}
\centering
\caption{ACES Revenue and LESS Capacities for Different Numbers of CESs in Microgrid}
\begin{tabular}{|c|c|c|c|c|}
\hline
Case & ACES Capacity & LESS Capacity & Total ACES Revenue & Individual ACES Revenue \\
\hline
Case w/ ACES & 4 MW & 4 MW & $435 / day & $217 / day \\
(\# of CES = 2) & /4 MWh & /15 MWh & & \\
\hline
Case w/ ACES & 6 MW & 2 MW & $652 / day & $217 / day \\
(\# of CES = 3) & /12 MWh & /9 MWh & & \\
\hline
Case w/ ACES & 2 MW & 6 MW & $217 / day & $217 / day \\
(\# of CES = 1) & /4 MWh & /21 MWh & & \\
\hline
\end{tabular}
\end{table}