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*Published in:*
Proceedings of IEEE Power and Energy Society General Meeting (PESGM), 2016

*DOI (link to publication from Publisher):*
10.1109/PESGM.2016.7741411

*Publication date:*
2016

*Document Version*
Early version, also known as pre-print

*Citation for published version (APA):*
Palizban, O., Kauhaniemi, K., & Guerrero, J. M. (2016). Evaluation of the hierarchical control of distributed Energy Storage Systems in islanded Microgrids based on Std IEC/ISO 62264. In *Proceedings of IEEE Power and Energy Society General Meeting (PESGM), 2016* IEEE Press.
https://doi.org/10.1109/PESGM.2016.7741411

# Evaluation of the Hierarchical Control of a Distributed Energy Storage System in Island Microgrids, Based on the IEC/ISO 62264 standard

Omid Palizban,*student member, IEEE*
Kimmo Kauhaniemi
Dept. Electrical Engineering and Energy Technology
University of Vaasa
Vaasa, Finland
{omid.palizban,Kimmo.Kauhaniemi}@Uva.fi

Josep M. Guerrero, *Fellow, IEEE*
Dept. Energy Technology
Aalborg University
Aalborg, Denmark
joz@et.aau.dk
www.microgrids.et.aau.dk

***Abstract*— In this paper, a decentralized control methodology based on hierarchical control levels is investigated. In recent years, efforts have been made to standardize microgrids (MGs), and the decentralized control method evaluated here is based on the IEC/ISO 62264 standard. Since the main challenge to decentralized control in Battery Energy Storage Systems (BESSs) is the different levels of stored energy, a modified droop control is used here to share the power between the different storage units, based on the energy level of each unit. The power coefficients of the droop control are set inversely proportionally and directly proportionally, respectively, to the state of charge (SoC) of each battery unit during discharging and charging mode. To evaluate this decentralized method based on the IEC/ISO 62264 standard, PSCAD/EMTDC software is used.**

***Index Terms*—** Decentralize control, Droop control, hierarchical control, IES/ISO62264 Standard, Microgrid.

## I. INTRODUCTION

Recently, with the growing use of renewable energy, Distributed Generation (DG) and consequently Microgrids have become more interesting system for implementation and research. Since the power produced by these sources is not stable and their response to variation within the MG is slow, an Energy Storage System (ESS) must be used to cover the fluctuation. The critical point in such a system is to control the MG and ESS by managing the power between these two different systems. To achieve the optimum operating performance for the system, a hierarchical control needs to be implemented. A comprehensive investigation of MGs is presented in [1], on the basis of which hierarchical control can be described as having four and three levels, respectively, for MGs and ESSs. The control levels are responsible for processing (*inner control loop*), sensing and adjusting (*primary level*), monitoring and supervising (*secondary level*), and maintaining and optimizing (*tertiary level*). However, energy storage is a local resource that generally contributes to the MG in island operating mode. The third control level thus does not operate and hierarchical control of ESSs consists of three levels: the inner, primary, and secondary control loops. Each control level can be implemented using a number of different technologies; *Vandoorn et al.* [2] and *Guerrero et al.* [3] present a complete investigation into the primary and secondary control level, respectively. Secondary control levels can be classified as *centralized* or *decentralized*, and the challenges of the control level, and their solution, is presented in [4]. The major challenges to employing a fully decentralized control system are the impossibility of controlling the system during transient variations and some other management functions. To solve these challenges and reach high level control, a distributed cooperative strategy for ESS and MG is proposed and evaluated by the authors in [5].

At the same time, over the last several years, researchers have been also working on obtaining standards for designing the most suitable overall MG. As shown in Fig. 1, a brief statistical study using the *web of science and IEEE xplore* search engine showed an increasing trend for research into hierarchical control in MGs and standardization in this area over the last ten years. There are no precise standards to have been developed for adapting MGs, but some Distributed Energy Resource (DER) standards can be used. In [6] a summary of the European and American standards applicable to MGs is presented. To approach this open research question, the authors of the paper proposed applying the international standard IEC/ISO 62264 to MGs and ESSs [7, 8], taking account of the hierarchical control of these systems. The IEC/ISO 62264 standard consists of five different levels: *level zero* (the generation process), *level one* (the process of sensing and adjusting generation), *level two* (monitoring and supervising), *level three* (maintaining and optimizing), and *level four* (market structure and business model).

The objective of this paper is to evaluate and adapt the proposed distributed control strategy for MGs [5] based on the IEC/ISO 62264 standard. A detail of the standard, are given in Section 2. In section 3, definition of the hierarchical control level and the methodology of the distributed control system are presented. The control method is adapted and evaluated on the basis of the IEC/ISO 62264 standard in Section 4. A simulation study is presented in Section 5 to evaluate the performance of the distributed control method. Finally, the paper is concluded in Section 6.

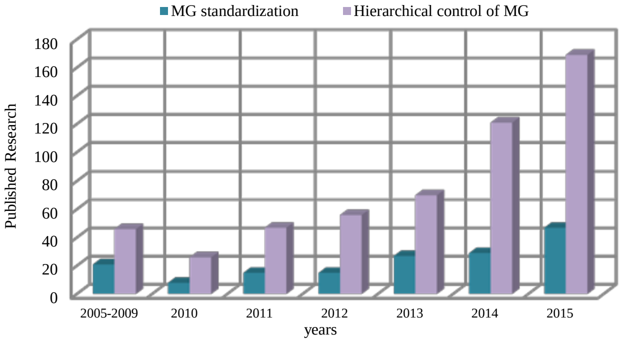

Fig.1 Statistics about hierarchical control and standardization of MG

## II. IEC/ISO 62264 STANDARD

As mentioned, the variation in power generation and interconnection, as well as the electrical interfaces between different sources, energy storage systems, and the main grid may be barriers to achieving a common standard for connecting DERs to the grid [6]. To address these issues, the IEC/ISO 62264 international standard is intended to be applied to MGs, which are considered here from a hierarchical control viewpoint. The objective of IEC/ISO 62264 is to offer consistent terminology for supplier and manufacturer communications, and thus to serve as a foundation for clarifying applications and information**.** IEC/ISO 62264 is represented on five levels [9]:

*Level zero* indicates the process of manufacturing or production and discusses the fundamental information and management. *Level one* specifies sensing, sensors, and actuators to monitor and regulate generation. In this level, direct control for providing stable output from units and the measurement of deviations in the response to each immediate variation in the system are discussed. Moreover, the collection of data and the transmission of the information to the upper control level are further objectives of this level.

*Level two* indicates the control activity for monitoring and supervising the process in order to keep it stable and under control. In this level, the information received from level one is analyzed to determine the limits of the system. Moreover, in this level, the position of the system is determined and, on the basis of this position, the control strategy aims to optimize the operation of the system. *Level three* creates a connection between two different part of the control system, taking into account the demand and detecting energy limitations. *Level four* concerns the market structure and business model of the system. In this level of the standard, the exchange of production between the generator and consumer, capital and how to exploit it, and consumer service are considered. Based on this standard, control of the system is in hierarchical form and all commands are executed by imposing them from a higher level.

## III. DECENTRALIZED CONTROL OF MGS & BESS

The DGs and Battery Energy Storage Systems (BESUs) are power electronic control-based devices that contain several parts with different responsibilities. The hierarchical control approach is necessary in such a system in order to achieve an optimum control strategy. The definitions and responsibilities of each control level of the power electronic base sources are as follows [10, 11]:

The *inner control loop* manages the output power of the sources as a target of the control level; this is accomplished by the inner current and voltage control loop. The *primary control* feeds the inner current and voltage control loop by adjusting the reference value of the frequency and voltage. The *secondary control* ensures a secure output from sources by supervising and monitoring the system for regulating the deviation of both voltage and frequency. The *Tertiary control* manages the power flow by adjusting the voltage and frequency when the MGs are connected to the main grid.

Since the objective of this paper is to adapt the IEC/ISO62642 standard to the decentralized control method for MG (DGs and BESSs), the distributed control strategy used in this paper is presented as follows [5]:

As proposed in [12], in distributed control methods for DGs, the error rate for the frequency and voltage is determined by comparing the measurements at regular intervals with the average value. The error rate is then sent to the primary control level to restore the voltage and frequency. The restoration compensator is determined as below:

$$\Delta V_{ESU_k} = G_{pv}(V_{ESU}^{ref} - \overline{V}_{ESU_k}) + G_{iv}\int(V_{ESU}^{ref} - \overline{V}_{ESU_k})dt$$
$$\overline{V}_{ESU_k} = \frac{\sum_{i=1}^{N} V_{ESU_i}}{N} \tag{1}$$

$$\Delta f_{ESU_k} = G_{pf}(f_{ESU}^{ref} - \bar{f}_{ESU_k}) + G_{if}\int(f_{ESU}^{ref} - \bar{f}_{ESU_k})dt$$
$$\bar{f}_{ESU_k} = \frac{\sum_{i=1}^{N} f_{ESU_i}}{N} \tag{2}$$

Since the voltage value is different in each part of the system, the reactive power of each sample point must be measured and considered in order to obtain the reference value for the primary control. The control signal for the reactive power is calculated as:

$$\Delta Q_{ESU_k} = G_{PQ}(\overline{Q}_{ESU_k} - Q_{ESU_K}) + G_{iQ}\int(\overline{Q}_{ESU_k} - Q_{ESU_k})dt$$
$$\overline{Q}_{ESU_k} = \frac{\sum_{i=1}^{N} Q_{ESU_i}}{N} \tag{3}$$

In these equations, $\Delta V_{ESU_k}$, $\Delta f_{ESU_k}$ and $\Delta Q_{ESU_k}$ are the restoration values of the voltage, frequency, and reactive power, respectively, while $\overline{V}_{ESU_k}$, $\bar{f}_{ESU_k}$ and $\overline{Q}_{ESU_k}$ are the average voltage, frequency, and reactive power of $ESU_k$ at each sample time. $G_p$ and $G_i$ are the control parameters of the upper control PI compensator for voltage (v), frequency (*f*), and reactive power (Q).

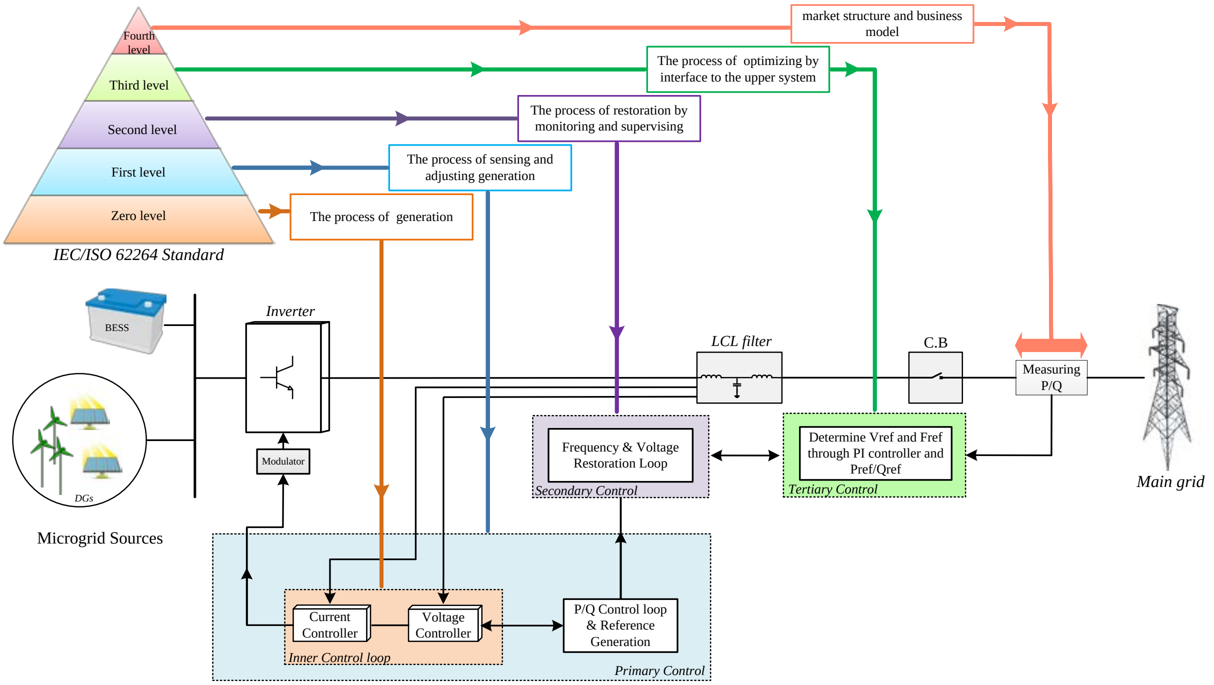

Fig.3 : Microgrid sources (DGs and BESS) Vs. IEC/ISO62264 Standard

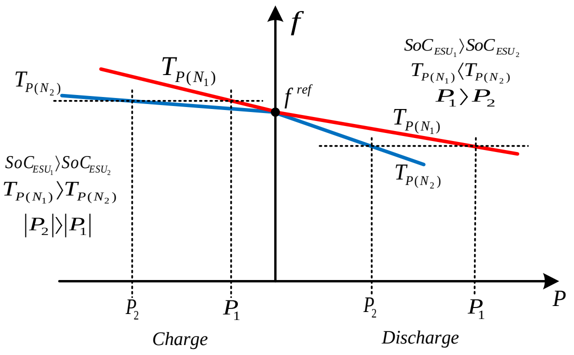

Fig.2 modified droop control

In a BESS, the energy level of each unit is different, and there is also variation from step to step. Hence, to adapt the decentralized method to the system, an accurate reference value based on the available energy of the system in each sample intervals is required.

The reference value for the energy level and the control signal for SoC in this decentralized control strategy are defined as [5]:

$$\delta_{SoC_{ESU_k}} = G_{PS}(So\overline{C}_{ESU_k} - SoC_{ESU_k}) + G_{is}\int(So\overline{C}_{ESU_k} - SoC_{ESU_k})dt$$

$$So\overline{C}_{ESU_k} = \frac{\sum_{i=1}^{N} SoC_{ESU_i}}{N} \quad (4)$$

In this equation, $\delta_{SoC_{ESU_k}}$ and $So\overline{C}_{ESU_k}$ are the control signal and the reference value for SoC, respectively. Moreover, the number of storage units shown with (N). Generally, in traditional droop control, the power from the storage unit is shared based on the power capacity of each unit. The strategy lead to some problems in the ESS control where the storage units that have lower energy levels will run out of energy earlier than the others in discharge mode, while BESUs with higher levels of energy become full and are no longer able to absorb energy during charging.

To overcome this problem, a modified droop control has been presented by the author in [5], on the basis of which power sharing between the BESSs takes account of the energy level of each unit. In this method, the droop coefficient is inversely proportional to the energy level during discharge and directly proportional during charging. The new droop coefficient ($T_{P(N_k)}$) and the modified droop control is obtained:

$$T_{P(N_k)} = \begin{cases} T_{P(S)} + \delta_{SoC_k} \longrightarrow \textit{Discharging mode} \\ T_{P(S)} - \delta_{SoC_k} \longrightarrow \textit{Charging mode} \end{cases} \quad (5)$$

$$f_k = f^{ref} - T_{P(N_k)}.(P_k - P^{ref}) \quad (6)$$

Fig. 2 shows the curve of the state-of-charge-based droop control. Power injection during discharge and the absorption of energy during charging is based on the energy level of each storage unit.

## IV. DICENTRALIZED CONTROL VS. IEC/ISO62264

Based on the definition of the different levels in the IEC/ISO 62264 standard and of decentralized control in DGs and BESSs, these two issues conform to each other here.

*Level zero of the IEC/ISO 62264 standard* considered the fundamental information on production units; the responsibility of DGs and BESSs in this level is to implement the *inner control loop* through voltage and current control loops so as to manage power inside the sources.

The *first level of the IEC/ISO 62264 standard* detects any variation in the system and acts to cover it immediately by measuring the difference and transferring it to the upper control level. In DGs and BESSs, determining accurate reference values for voltage and frequency so as to maintain optimum control of the power converter is the responsibility of the *primary control level*. Since the *second level of the IEC/ISO 62264 standard* monitors and supervises the system to keep it stable and under control, the *second control level* in DG and BESS hierarchical control can be covered by the standard level. Monitoring and supervising the variations in power, voltage, and frequency—as well as determining the reference value for the primary control based on the variation—are the responsibility of the control level. The duties of the third level of the IEC/ISO 62264 standard are to create a program to manage the coverage area and produce the optimize strategy to support the subsystem, and the objectives of the tertiary control level in DGs and BESSs is power management and the reinstatement of secondary control. Moreover, optimizing the set-point operation of the system from both technical and economic points of view is the other objective of the final level of control in the MG, with the *fourth level of the IEC/ISO 62264 standard* discussing the market structure and the business mode of system. The adaptation of decentralized control and the proposed standard are illustrated in Fig. 3.

Although the structure of control is same for both DGs and BESSs, however, there are some differences in responsibility of hierarchical control between them. The responsibility of the hierarchical control of MGs is to provide stable power for connecting to the main grid or supporting the linear and nonlinear loads. Hierarchical control is defined based on the type of the connection for the MG—however, as mentioned in the introduction, storage control does not contain tertiary controls but consists only of an inner control loop, primary, and secondary control levels. The responsibility of the hierarchical control of a BESS, in addition to providing stable power, is managing the energy level of the energy storage system and avoiding the problems overcharging or over discharging. The following section evaluates the decentralize control strategy, is discussed in Section 3, for the charging and discharging period when there is a difference in energy levels based on IEC/ISO 62264 standard.

## V. SIMULATION STUDY

PSCAD/EMTDC is used to simulate the distributed cooperative control of BESSs and DGs based on the IEC/ISO 62264 standards. The system include three battery storage units which is adjusted by 5% difference in their energy level for both charging and discharging mode, so that $SoC_{ESU_1}\rangle SoC_{ESU_2}\rangle SoC_{ESU_3}$. Moreover, to achieve an advanced simulation, each DG and BESS is in a different location with different distances between them (*200 m*, *150 m*, and *100 m* to the AC bus for BESU$_1$ to BESU$_3$ and DG$_1$ to DG$_3$, respectively). Two resistors ($R_{L1}$, $R_{L2}$), acting as the linear load and nonlinear load, is included with a diode rectifier loaded by a capacitor $(C_{NL})$ and a resistor load ($R_{NL}$) used to connect to the AC bus. The entire load is located *50 m* away from the AC bus. The configuration of the system is shown in Fig. 4 and Table 1 summarizes its main parameters, which are identical for all three BESUs and DGs.

As mentioned, the hierarchical control of BESSs based on the IEC/ISO 62264 standard, besides providing stable power, is also responsible for injecting power during power shortages (discharging mode) and absorbing energy to charge storage units (charging mode). Equalization of the energy levels for each battery storage unit for discharging and charging are shown in Fig. 5. The power is shared in such a way that the unit with the greatest SoC (Battery 1) provides more power than the unit with the least SoC (Battery 3), when storage unit operate as a power supplier. The situation is inverted when power is absorbed through these storage units. Fig. 6 shows the absorbed and injected power of each unit in the process of discharging and charging. In power sharing, the difference between the powers is reduced gradually, based on the closing energy level of each unit. The speed of convergence decreases with each step on account of the decreasing error values between the power shared and the SoC. The low fluctuations in injected and absorbed power in the storage unit are a result of the hierarchical control level of the MG, which is evaluated on the basis of the IEC/ISO 62264 standard here. The variation in the power absorbed is higher than that of the injecting power because of the variation in the power generated by the DGs.

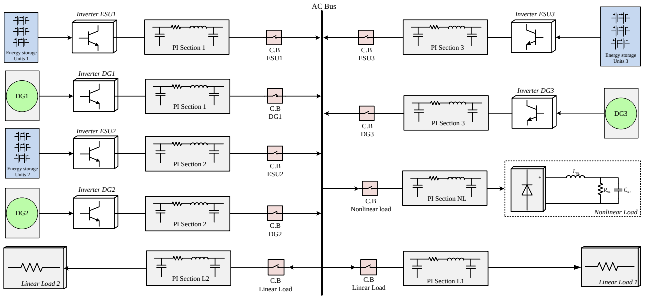

Fig.4 The system study for simulation

Table.1 Simulation parameters

| type | Item | Symbol | Values |
|---|---|---|---|
| Secondary level control | Amplitude voltage proportional term | $G_{PV}$ | $0.2\times10^{3}$ |
| | Amplitude voltage Integral term | $G_{iV}$ | $0.1\times10^{-2}$ |
| | Frequency proportional term | $G_{Pf}$ | $0.1\times10^{-2}$ |
| | Frequency Integral term | $G_{if}$ | $0.2\times10^{3}$ |
| | Reactive power proportional term | $G_{PQ}$ | $0.1\times10^{3}$ |
| | Reactive power Integral term | $G_{iQ}$ | $0.2\times10^{-3}$ |
| | SoC proportional term | $G_{PS}$ | $0.2\times10^{3}$ |
| | SoC Integral term | $G_{iS}$ | 3 |
| Load | Linear load | $R_{LL}$ | $200\Omega$ |
| | Nonlinear load resistance | $R_{NL}$ | $200\Omega$ |
| | Nonlinear load inductance | $L_{NL}$ | 0.084 mH |
| | Nonlinear load capacitance | $C_{NL}$ | $235\mu f$ |

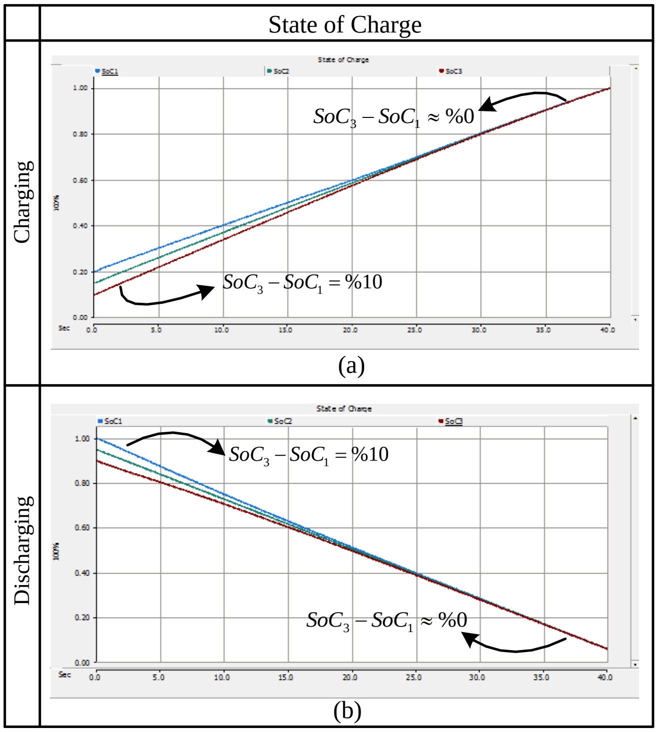

Fig.5: Converge of SoC (a) charging mode (b) discharging mode

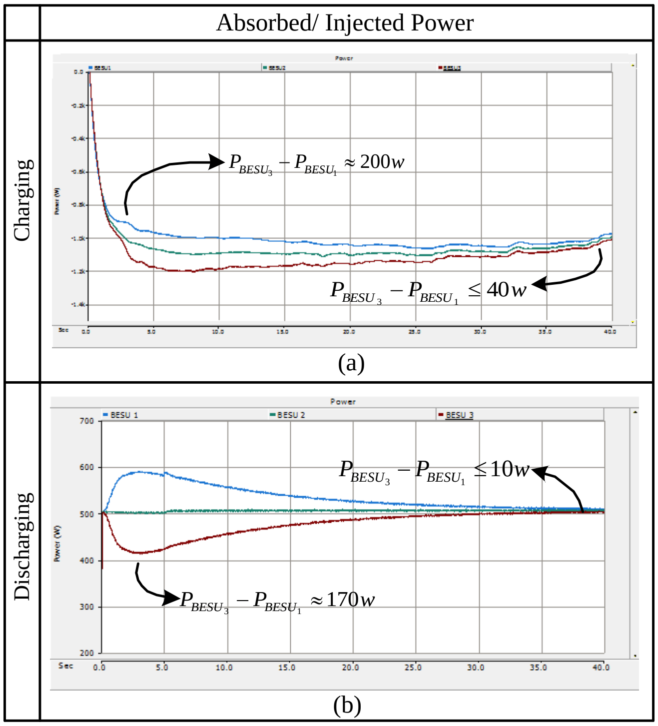

Fig.6: power sharing (a) charging mode (b) discharging mode

## VI. CONCLUSION

In this paper, a decentralized control method for microgrids has been described in conformity to the IEC/ISO62264 standard. To deal with the challenge represented by the difference in energy levels between the storage units, a modified droop control with the ability to share the power between the different units based on their energy levels in the decentralized control is employed. The benefit of decentralized control of MGs is the improvement in the efficiency of the distributed cooperative control of DGs and ESSs, as well as the increase in the power reliability of the system. The hierarchical control of MGs with decentralized control is evaluated based on the IEC/ISO62264 standard. The standardization involves the target of each control level and does not depend on details such as the type of control. Hence, the standardization can be extended to other control types of microgrid. The investigation of decentralized control in different ESS applications remains an open research question for future work.

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