

Decoupling-based Withdrawal Scheme to Enhance Resilience of Multi-agent Energy Storage Systems under Contingencies

Shaohua Yang

State Key Laboratory of
Internet of Things for Smart City;
Department of Electrical and Computer
Engineering, University of Macau
Macao, China
yc17436@um.edu.mo

Keng-Weng Lao

State Key Laboratory of
Internet of Things for Smart City;
Department of Electrical and Computer
Engineering, University of Macau
Macao, China
johnnylao@um.edu.mo

Hongxun Hui

State Key Laboratory of Internet
of Things for Smart City;
Department of Electrical and Computer
Engineering, University of Macau
Macao, China
hongxunhui@um.edu.mo

Yulin Chen

Hainan Institute of Zhejiang University
Sanya, China
chenyl2017@zju.edu.cn

Abstract—Renewable energies (RENs) are growing as never before due to climate concerns. Energy storage system (ESS) is regarded as a promising solution to help the power grid integrate RENs. However, the ESS is increasingly evolving into cyber-physical deeply coupled systems that are vulnerable to cyber-physical security risks. In this paper, we consider potential contingency in the ESS, and formulate the contingency problem by combining the characteristic of cyber-physical interactions. On this basis, it is revealed that a contingency at the physical layer may cause wrong information misleadings at the cyber layer, which can in turn lead to the normal energy storage devices in the ESS being out of control. Furthermore, we develop a decoupling-based withdrawal scheme to guarantee the normal operation of the whole ESS, even under contingency. Finally, the effectiveness of the proposed scheme is verified in case studies. Results show that a physical-layer contingency can cause topology decomposition, which can further result in the failure of the ESS to provide flexibility services to the power grid. While with the proposed scheme, all remaining energy storage devices in the ESS can still operate normally, despite the contingency in some devices. Therefore, the proposed scheme contributes to the enhancement of the resilience of ESS.

Index Terms—Cyber-physical system, energy storage system, contingency, resilience enhancement

I. INTRODUCTION

Nations worldwide are actively engaged in concerted efforts to reduce carbon emissions and transition towards renewable energies (RENs) to address the challenges posed by climate change [1]. This transition is driven by the recognition of the adverse environmental impacts associated with traditional fossil fuels, as well as the efficacy of REN solutions [2]. The increasing penetration of RENs is leading

to dramatic changes in power grids [3]. For example, the share of traditional generators in power grids is decreasing, which implies that less reliance is being placed on high-carbon energies, while less flexibility services can be provided by traditional generators [4]. Moreover, RENs, e.g., wind turbines and photovoltaics, are naturally stochastic and variable, and thus the increased RENs also introduce additional uncertainty and power fluctuations into power grids [5]. Power fluctuations are more serious but without sufficient flexibility services to hedge against them, which causes severe challenges to the safety of power grid operations [6].

In order to meet the growing requirement for flexibility services and bolster the safety of the power grid, energy storage system (ESS) has emerged as a promising and energetic solution [7]. Specifically, ESS is an entity that participates in the operation of the power grid by aggregating adjustable battery energy storage devices [8]. It harnesses the potential of these storage devices to mitigate the problems of peak-to-valley differences [9]. For this reason, ESS contributes significantly to improving the integration of RENs in power grids, which supports the achievement of carbon reduction targets as well as ensuring the safe and reliable operation of power grids [10]. Furthermore, thanks to advancements in computation, communication, control (3C), and Internet of Things (IoTs) technologies, energy storage devices in ESS can better cooperate with each other, and the multi-agent ESS is becoming larger in scale with superior performance [11]. Consequently, an increasing number of ESSs are actively engaging with power grids, gradually becoming indispensable components of the power grids. This highlights the critical need for ensuring the safe operation of these BSSs.

However, the numerous decentralized energy storage devices aggregated in the ESS are inevitably subject to un-

This work was partly supported by The Science and Technology Development Fund, Macau SAR (File/Project no. SKL-IOTSC(UM)-2021-2023, 0003/2020/AKP, and FDCT/0022/2020/A1).

foreseen contingencies, such as physical damage, emergency maintenance downtime, and so on [12]. It is referred to as faulty devices in this paper. It should be noted that, because of the applied 3C and IoTs technologies, the cyber and physical layers of the ESS are coupled to each other, which means the shutdown or damage to the physical layer of a device can affect the cyber layer [13]. Meanwhile, at the cyber level, there are communication interactions between different energy storage devices, which can further propagate and worsen the adverse effects [14]. As a result, there will be a large number of energy storage devices suffering from wrong information, leading to control problems of energy storage devices in the physical layer, and ultimately resulting in the failure of entire multi-agent ESS control. That means the faulty devices can bring high risk to the entire information-technology-based ESS. To avoid the cyber-physical risk, removing the individual faulty devices from the ESS is an option. However, this option could introduce the more severe problem of communication topology decomposition at the cyber level, leading to more energy storage devices getting out of control. Therefore, it is imperative to develop a more resilient scheme for ensuring the safe operation of ESS in the event of a possible contingency in energy storage devices.

To address this issue, a decoupling-based withdrawal scheme is proposed in this paper, which can ensure the implementation of safe control for ESS in the presence of contingency.

The remainder of this article is organized as follows. In Section II, the model and control of ESS is given. In addition, the control problem of the ESS is formulated considering the contingency. In Section III, a novel decoupling-based withdrawal scheme is developed to enhance the resilience of ESS. Case studies can be found in Section IV, and then, this paper is concluded in Section V.

II. MODEL AND CONTROL OF ENERGY STORAGE SYSTEM CONSIDERING CONTINGENCY

In this part, the modeling of ESS is given first. Then, the control problem is formulated for the ESS considering contingency. The framework of a cyber-physical ESS in the power grid can be illustrated in Fig. 1. As seen in Fig. 1, the ESS composes physical and cyber layers. The physical layer is an entity that can contain a variety of energy storage devices, here exemplified by battery energy storage (BES), and can directly provide flexibility services to the power grid. In the cyber layer, information exchange is realized between each BES device, which makes the entire ESS capable of dynamically responding to flexibility service requirements well-coordinatedly. The cyber-physical coupled ESS can help the power grid to effectively accommodate power fluctuations, thereby improving the flexibility and resilience of the power grid.

A. Modeling of Energy Storage System

The state of charge (SoC) of each BES can be estimated by using the basic Coulomb counting method [15], which can be

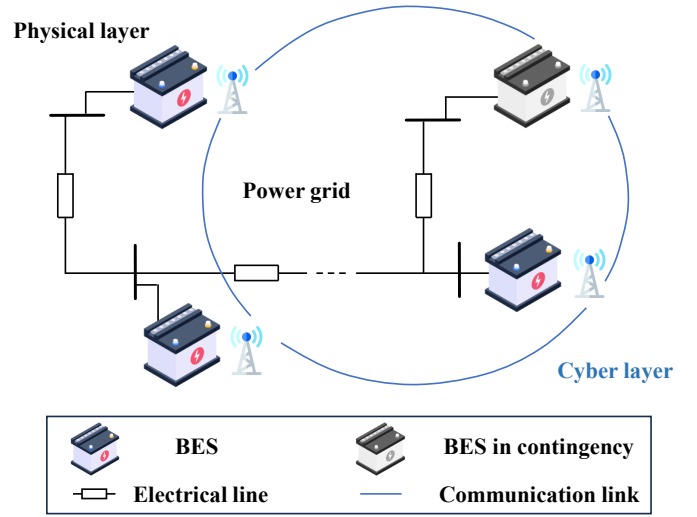


Fig. 1. Cyber-physical energy storage system in the power grid considering contingency.

expressed as follows:

$$S_k(t) = S_k(0) + \frac{\eta_k}{Q_k} \int I_k(t) dt, k = 1, \dots, N, \quad (1)$$

where $S_k(t)$ represents the SoC of the BES k at time t , $S_k(0)$ is the initial SoC status, Q_k denotes the capacity of the BES k , I_k is the output current of the BES k , and η_k can be defined as:

$$\eta_k = \begin{cases} \eta_{c,k}, & \text{charging} \\ \eta_{d,k}, & \text{discharging} \end{cases}, \quad (2)$$

where $\eta_{c,k}$ and $\eta_{d,k}$ are the Coulombic efficiency in charging and discharging mode, respectively.

Reformulating (1) by the differentiation, it has:

$$\dot{S}_k(t) = -\frac{\eta_k}{Q_k} I_k(t), k = 1, \dots, N, \quad (3)$$

Since the power output of BESs is a direct variable in the flexibility services for power grids, the BES's power output is the main concern of the power grid, which can be obtained as follows:

$$P_k(t) = V_k I_k(t), k = 1, \dots, N, \quad (4)$$

where P_k is the power output of the BES k , and V_k is the output voltage of the BES k . Assume that the output voltage of each BES can remain constant in a large range of SoC. Based on this, the model of BES can be represented by using the variable P_k as follows:

$$\dot{S}_k(t) = -\frac{\eta_k P_k(t)}{Q_k V_k}, k = 1, \dots, N, \quad (5)$$

Assume that there are N BESs in the ESS, and the capacity of the flexibility services required by the power grid is P_{req} , where P_{req} should be provided by N BESs in the ESS

collectively. In this way, the total power of N BESs P_{tl} should satisfy the required capacity, which can be shown as follows:

$$P_{\text{tl}} = \sum_{k=1}^N P_k = P_{\text{req}}, \quad (6)$$

Based on this relationship in (6) and the principle of fair share, the power value to be achieved by each BES can be calculated by the ESS's manager. The manager can transmit this information as an instruction described in the state of power (SoP) for further the distributed consensus control of BSS.

B. Preliminaries for Distributed Control of ESS

A multi-agent ESS considering contingency can be mapped on a communication topology \mathcal{G} , consisting of N BESs with a leader vertex and some BESs in contingency. Each BES receives relative information from neighboring BES through the communication topology, including the cooperative BESs and the leader, as well as the BES in contingency. The leader vertex directly receives the reference value from the control center and can indirectly affect local control. The BES in contingency also indirectly affects local control since it propagates wrong information into the communication topology. The sets of BESs and the BES in contingency are represented as $\mathcal{I} = \{1 \leq i \leq N \mid i \in \mathbb{Z}\}$ and \mathcal{C} , respectively.

The communication topology for the ESS can be shown by $\mathcal{G} = (\mathcal{W}, \mathcal{E})$, where $\mathcal{W} = \{w_1, w_2, \dots, w_N\}$ is the set of vertexes and $\mathcal{E} \subseteq \mathcal{W} \times \mathcal{W}$ is the set of edges. Each vertex w_i is associated with the BES i . Each edge $(w_i, w_j) \in \mathcal{E}$ represents a information flow from the BES w_i to the BES w_j , where vertex w_i and vertex w_j are neighbors. The set of all the neighbors of vertex w_i is defined as $\mathcal{N}_i = \{w_j \mid (w_i, w_j) \in \mathcal{E}\}$.

The adjacency matrix $\mathcal{A} = [a_{ij}]$ of a graph \mathcal{G} can be defined with N dimensions, where a_{ij} represents the weight of edge (w_i, w_j) and can be shown as follows:

$$\begin{cases} a_{ij} = 1, & \forall (w_i, w_j) \in \mathcal{E}, \\ a_{ij} = 0, & \text{otherwise.} \end{cases} \quad (7)$$

The Laplacian matrix \mathcal{L} of a graph \mathcal{G} is defined by:

$$\mathcal{L} = \mathcal{D} - \mathcal{A}, \quad (8)$$

where \mathcal{D} is the in-degree matrix defined as $\mathcal{D} = \text{diag}\{\mathbf{d}\} \subseteq \mathbb{R}^{N \times N}$ with $\mathbf{d} = [d_1, d_2, \dots, d_N]^T$ and $d_i = \sum_{j \in \mathcal{N}_i} a_{ij}$. In addition, $\mathcal{B} = \text{diag}\{b_i\}$, $\forall i \in \mathcal{I}$ is the diagonal matrix of pinning gain, where b_i represents the pinning gain of the leader vertex. If there exists a link from the manager to the BES i , $b_i > 0$; otherwise, $b_i = 0$.

C. Control Problem of ESS Considering Contingency

The control object is the SoP of BESs. This is because the BES's power is the direct variable to be regulated for the power grid. In addition, the SoP is suitable as an information exchange between neighbor interconnected BESs, enabling large-scale BESs in the ESS to participate in distributed control in a fair manner. It is worth noting that the SoC is also an

important factor in the ESS operation, but it is assumed that the SoC is in the normal range, in order to focus more on the problem of cyber-physical security risk, which is the main concern in this paper.

Generally, under normal conditions, the SoP of BES can be regulated according to the control signal u_i , so as to complete the flexibility service requirements of the power grid. However, when a contingency occurs in the BES i , the SoP of the BES i will no longer depend on the control signal, which can be represented as follows:

$$\begin{cases} \theta_i = \Upsilon, & \forall i \in \mathcal{C}, \\ \theta_i = f(u_i), & \forall i \in \mathcal{I} \ \& \ \forall i \notin \mathcal{C}, \end{cases} \quad (9)$$

where θ_i is the SoP of the BES i ; Υ is a constant value, depending on the type of contingency; $f(u_i)$ is a function of control input. Moreover, a constant value of θ_i implies that its corresponding actual control input u_i is 0, which can be expressed as follows:

$$u_i = 0, \forall i \in \mathcal{C}, \quad (10)$$

Assuming that the SoP does not touch the saturation boundary, the control input u_i of BES i considering contingency can be expressed as follows:

$$u_i = -k \left(\sum_{j \in \mathcal{N}_i} a_{ij}(\theta_i - \theta_j) + b_i(\theta_i - \theta_{\text{mng}}) \right), \quad \forall i \in \mathcal{I} \ \& \ \forall i \notin \mathcal{C}, \quad (11)$$

where k is a coupling gain; θ_{mng} is the instruction signal from manager.

It is worth noting that even if no direct contingency occurs in the BES, its control signals can be indirectly affected when a contingency occurs in other BESs in the system. This is because for BESs in the system, the control input in (11) is computed by using neighborhood information, which may be indirectly affected by the contingency.

If there is no contingency, then the dynamics of SoP in the matrix form can be represented as follows:

$$\dot{\boldsymbol{\theta}} = -k(\mathcal{L} + \mathcal{B})\boldsymbol{\theta} + k\theta_{\text{mng}}\mathcal{B}\mathbf{1}_N, \quad (12)$$

where $\boldsymbol{\theta} = [\theta_1, \theta_2, \dots, \theta_N]^T$ is the SoP state vector; $\mathbf{1}_N$ is the N -dimensional vector filled with 1 entries.

According to the (12), it is known that the $\boldsymbol{\theta}$ can be stable since the state transition matrix is a positive-definite. In addition, the SoP can stabilize at the instruction signal from the manager, i.e., $\forall i \in \mathcal{I}, \theta_i \rightarrow \theta_{\text{mng}}$.

Problem: However, when there is a contingency, this matrix form of expression in (12) becomes incorrect due to some whole rows of the matrix becoming zero. This means that the original analysis method is invalid, and the steady state value of SoP solved by the original method is no longer correct. How to guarantee that normal BESs are unaffected, while still working in cooperation to meet the power grid's requirements during contingencies, is an urgent problem to be solved.

III. DECOUPLING-BASED WITHDRAWAL SCHEME FOR ESS UNDER CONTINGENCIES

In order to avoid the adverse effect of contingency on the ESS control, a decoupling-based withdrawal scheme is developed in this part. This scheme can protect the global control of the BES-based ESS, so as to provide reliable flexibility services to the power grid even under contingency.

Specifically, the decoupling-based withdrawal scheme can be described as the following. The cyber layer of the BES in contingency shall first be decoupled from the physical layer. Moreover, the BES device entity in contingency should be withdrawn from the physical layer of the ESS, while the cyber layer of this BES is retained in the system. In addition, the cyber layer of this BES shall also be adjusted as follows to cope with the topology change caused by the withdrawal of the physical layer.

The withdrawal in the physical is to avoid affecting other BESs. And due to decoupling, the cyber layer of this faulty BES will no longer receive wrong information from the physical layer. This also means the wrong information exchanges between this faulty BES and its neighbors are terminated. In addition, the cyber layer of this faulty BES should retain and support its original neighbors in transmitting information to each other. In this way, not only can the propagation of the adverse effects of contingency be avoided, but the unnecessary communication topology decomposition problem can also be solved. The decoupling-based withdrawal scheme can be captured in the adjacency matrix, and elements of the new adjacency matrix can be expressed as follows:

$$a_{ij} = \begin{cases} 1, & [\forall (w_i, w_j) \notin \mathcal{E} \wedge \forall i \notin \mathcal{C} \wedge \forall j \notin \mathcal{C} \wedge ((\forall i \in \mathcal{N}_{c_1} \wedge \forall j \in \mathcal{N}_{c_1}) \vee (\forall i \in \mathcal{N}_{c_2} \wedge \forall j \in \mathcal{N}_{c_2}) \vee \dots \vee (\forall i \in \mathcal{N}_{c_n} \wedge \forall j \in \mathcal{N}_{c_n}))], i \neq j] \vee [\forall (w_i, w_j) \in \mathcal{E} \wedge \forall i \notin \mathcal{C} \wedge \forall j \notin \mathcal{C}] \\ 0, & \text{otherwise.} \end{cases} \quad (13)$$

Correspondingly, the Laplace matrix, and the pinning matrix are also adjusted as $\hat{\mathcal{L}}$ and $\hat{\mathcal{B}}$, respectively. Based on this, the dynamics of the rest normal BESs in the matrix form can be given:

$$\dot{\theta} = -k(\hat{\mathcal{L}} + \hat{\mathcal{B}})\theta + k\theta_{\text{mng}}\hat{\mathcal{B}}\mathbf{1}_N, \quad (14)$$

According to (14), the θ can be stabilize at the instruction signal from manager, i.e., $\forall i \in \mathcal{I} \ \& \ \forall i \notin \mathcal{C}, \theta_i \rightarrow \theta_{\text{mng}}$. This means that despite BESs suffering from contingencies, the remaining BESs can still work well in collaboration to perform the power grid's flexibility service tasks well-coordinatedly.

IV. CASE STUDY

A. Test System

This part examines the performance of the proposed decoupling-based withdrawal scheme in an ESS with 8 BESs. Considering the critical location, the No. 5 BES is assumed to be subject to unforeseen contingency. In particular, the

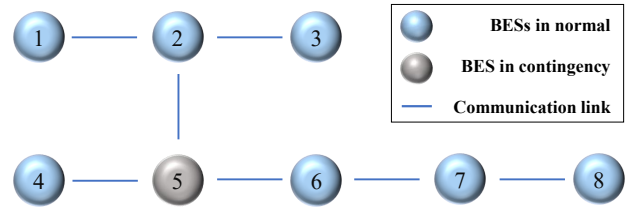


Fig. 2. The Communication Topology Used in Case Study.

networked multi-BESs system can be depicted in Fig. 2, whose Laplacian matrix can be shown as:

$$\mathcal{L} = \begin{bmatrix} 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 \\ -1 & 3 & -1 & 0 & -1 & 0 & 0 & 0 \\ 0 & -1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 \\ 0 & -1 & 0 & -1 & 3 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 & 2 & -1 & 0 \\ 0 & 0 & 0 & 0 & 0 & -1 & 2 & -1 \\ 0 & 0 & 0 & 0 & 0 & 0 & -1 & 1 \end{bmatrix}. \quad (15)$$

In Fig. 2, the blue vertexes represent BESs in normal, and the gray vertex represents the BES in contingency. The test process is as follows: at the beginning, each BES has a different initial value of SoP; during 0-100 seconds, the distributed consensus control is executed normally according to the instruction; at 100 seconds, the No.5 BES (the faulty BES) is subject to unforeseen contingency and out of control, lasting to the end; at 200 seconds, the power grid's requirements change, which is reflected in the instruction change for the BES-based ESS; the test ends at 300 seconds.

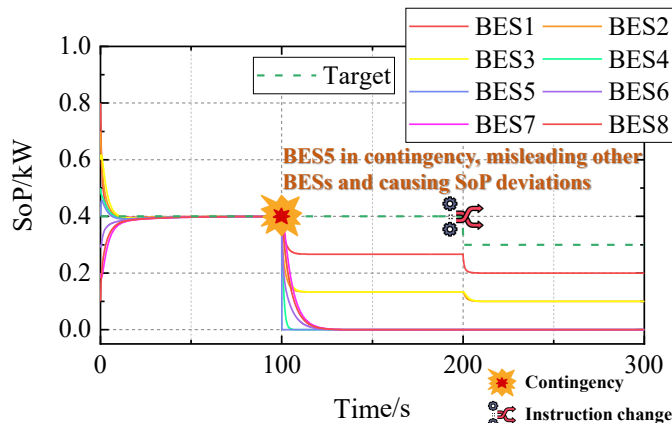
There are three cases in this section: (i) Case 1: Contingency Effect on ESS without taking any action; (ii) Case 2: Contingency Effect on ESS by removing the faulty BES; (iii) Case 3: Contingency Effect on ESS by using the proposed scheme.

B. Contingency Effect on ESS without Taking Any Action

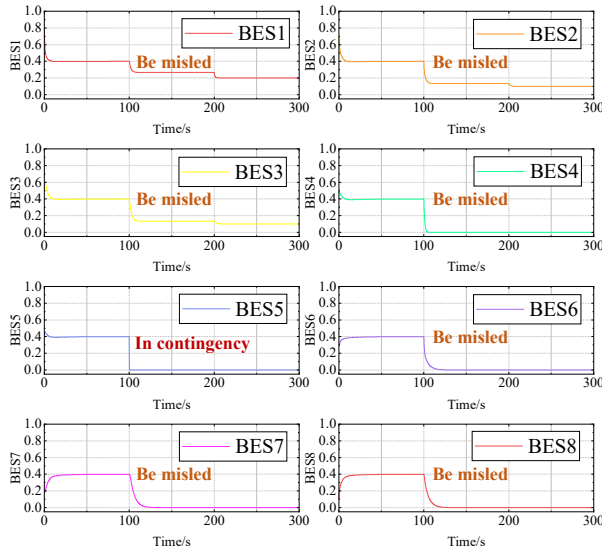
In this case, the contingency effect on BESs in the ESS without taking any action is shown in Fig. 3. From Fig. 3 (a), it can be seen that during 0-100 seconds, the SoP of each BES can converge to the instruction signal from the manager. This means that the BES-based ESS can provide flexibility with the power grid on request. However, during 100-200 seconds, it can be observed that the consensus convergence fails for different BESs due to the contingency on the No.5 BES. Moreover, during 200-300 seconds, the instruction has been changed, but the consensus convergence failure is continuous.

Moreover, from Fig. 3 (b), it can be seen that during 0-100 seconds, each BES's SoP is regulated from different initial values to the instruction signal. However, when a contingency occurs in No.5 BES, the SoP of No.5 BES immediately becomes zero. The SoP of No.4, 6, 7, and 8 BESs is misled and gradually reaches zero as well. The SoP of No.1, 2, and 3 BESs is also misled and deviates from the instruction signal.

This case shows that when a contingency occurs, all BESs in the ESS will be misled, and the consensus control will be



(a) The overall diagram: consensus convergence failure.



(b) Diagrams for individual BES: all remaining BESs are misled.

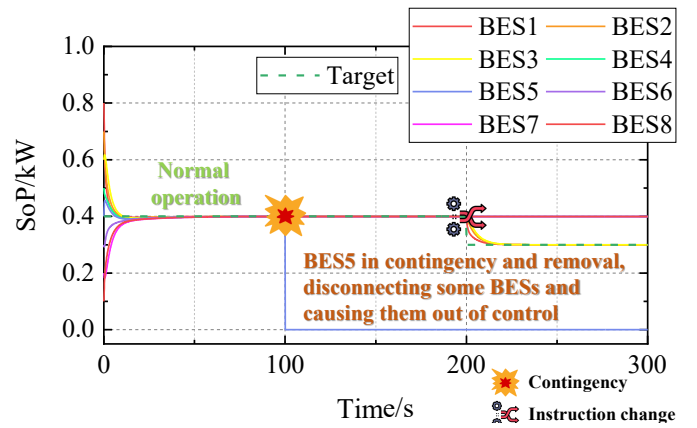
Fig. 3. Performance of BESs in ESS under contingency without taking any action.

failed. This indicates that the ESS is no longer capable of meeting the requirements of the power grid.

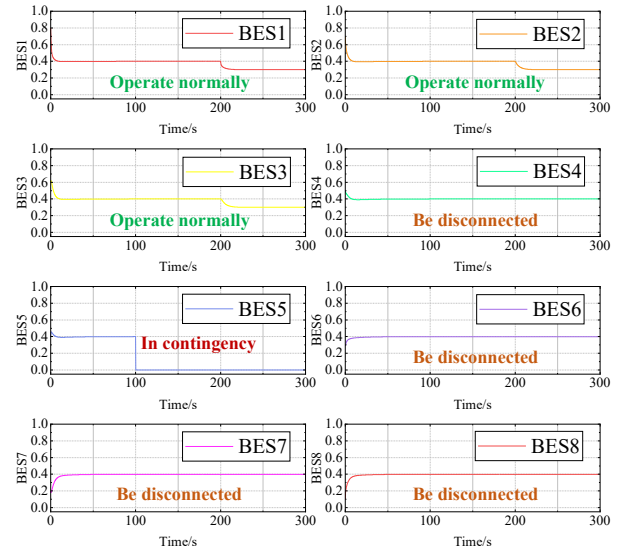
C. Contingency Effect on ESS by Removing the Faulty BES

In this case, the performance of the BESs by removing the faulty BES is shown in Fig. 4. From Fig. 4 (a), it can be seen that during 0-100 seconds, the SoP of each BES can also converge to the instruction signal from the manager, as in the first case. The difference is that during 100-200 seconds, the consensus convergence of each BES is maintained despite the contingency on the No.5 BES. However, during 200-300 seconds, it can be observed that the consensus convergence fails for each BES due to the instruction change.

In addition, from Fig. 4 (b), it can be seen that during 0-100 seconds, each BES's SoP is also regulated from different initial values to the instruction signal. When a contingency occurs in No.5 BES, the SoP of No.5 BES immediately becomes zero. But the SoP of all remaining BESs can still keep the instruction signal state for up to 200 seconds. Moreover, after the instruction change at 200 seconds, No.1, 2, and 3 BESs



(a) The overall diagram: consensus convergence failure.



(b) Diagrams for individual BES: some remaining BESs are misled.

Fig. 4. Performance of BESs in ESS under contingency by removing the faulty BES.

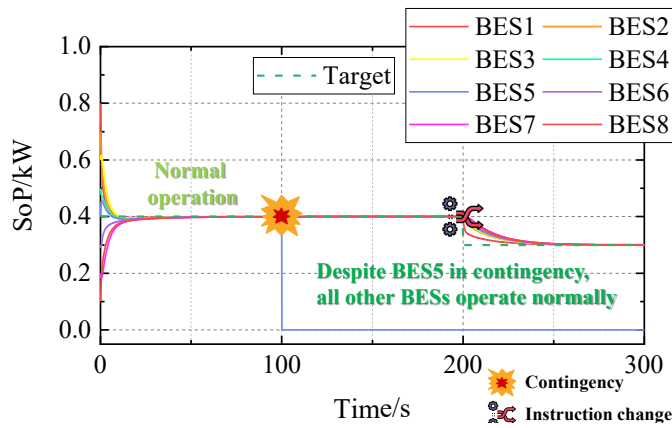
can still track the changed instruction signal, but No.4, 6, 7, and 8 BESs are out of control and can only remain in their previous state.

This case shows that some BESs still function normally when a contingency occurs, and the removal action is taken. However, some BESs are out of control due to topology deconstruction, which can result in the failure of the ESS to provide flexibility services to the power grid.

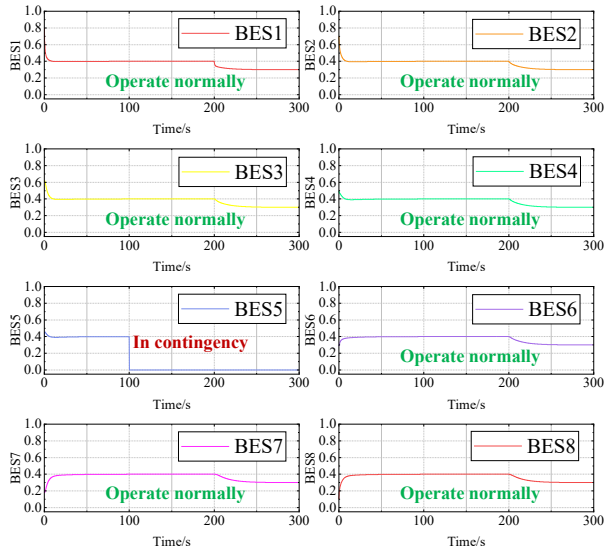
D. Contingency Effect on ESS by Using the Proposed Scheme

In this case, the performance of the BESs by using the proposed scheme is shown in Fig. 5. From Fig. 5 (a), it can be seen that the SoP of each BES can always converge to the instruction signal from the manager throughout the entire process, despite the presence of contingency. At 200 seconds, the instruction changes, and the SoP of each BES also gradually converges to the changed instruction signal state.

In addition, from Fig. 5 (b), it can be seen that at 100 seconds, a contingency occurs in No.5 BES, and the SoP of No.5 BES immediately becomes zero. However, the SoP of all



(a) The overall diagram: consensus convergence can still be achieved.



(b) Diagrams for individual BES: all remaining BESs function well.

Fig. 5. Performance of BESs in ESS under contingency by using the proposed scheme.

remaining BESs can still keep the instruction signal to respond to the power grid. Moreover, at 200 seconds, the instruction signal changes into another value, and the SoP of all remaining BESs can still track the new value after a short adjustment period.

This case shows that using the proposed scheme, all remaining BESs in the ESS can still work well, despite the contingency.

V. CONCLUSION

The ESS is an essential power grid component with high penetration RENs. The abnormal operation of ESSs will threaten the safe and stable operation of the power grid. However, contingencies inevitably arise in ESSs. This paper takes into account the characteristics of cyber-physical interactions and formulates the problem that contingency can cause severe impacts on the ESS. In addition, a decoupling-based withdrawal scheme is developed to enhance the resilience of the ESS in case of contingency. Case study results demonstrate that contingency can cause misinformation and topology de-

composition, which can further lead to more energy storage devices going out of control. However, with the proposed scheme, despite the contingency, all remaining BESs in the ESS can still function well. Hence, the proposed scheme can enhance the resilience of ESS.

REFERENCES

- [1] Y. Wang, R. Wang, K. Tanaka, P. Ciais, J. Penueles, Y. Balkanski, J. Sardans, D. Hauglustaine, W. Liu, X. Xing, *et al.*, "Accelerating the energy transition towards photovoltaic and wind in China," *Nature*, vol. 619, no. 7971, pp. 761–767, 2023.
- [2] Y. Chen, D. Qi, H. Hui, S. Yang, Y. Gu, Y. Yan, Y. Zheng, and J. Zhang, "Self-triggered coordination of distributed renewable generators for frequency restoration in islanded microgrids: A low communication and computation strategy," *Adv. Appl. Energy*, vol. 10, p. 100128, 2023.
- [3] S. Yang, K.-W. Lao, H. Hui, Y. Chen, and N. Dai, "Real-time harmonic contribution evaluation considering multiple dynamic customers," *CSEE J. Power Energy Syst.*, Early Access, 2023.
- [4] H. Hui, P. Siano, Y. Ding, P. Yu, Y. Song, H. Zhang, and N. Dai, "A transactive energy framework for inverter-based HVAC loads in a real-time local electricity market considering distributed energy resources," *IEEE Trans. Ind. Informat.*, vol. 18, no. 12, pp. 8409–8421, 2022.
- [5] P. Wang, Z. Zhang, T. Ma, Q. Huang, and W.-J. Lee, "Parameter calibration of wind farm with error tracing technique and correlated parameter identification," *IEEE Trans. Power Syst.*, vol. 38, no. 6, pp. 5200–5214, 2023.
- [6] S. Yang, K.-W. Lao, H. Hui, and Y. Chen, "A robustness-enhanced frequency regulation scheme for power system against multiple cyber and physical emergency events," *Appl. Energy*, vol. 350, p. 121725, 2023.
- [7] A. Bharatee, P. K. Ray, A. Ghosh, and M. R. Jena, "Active power sharing scheme in a PV integrated DC microgrid with composite energy storage devices," *IEEE Trans. Power Syst.*, Early Access, 2023.
- [8] H.-C. Jo, G. Byeon, J.-Y. Kim, and S.-K. Kim, "Optimal scheduling for a zero net energy community microgrid with customer-owned energy storage systems," *IEEE Trans. Power Syst.*, vol. 36, no. 3, pp. 2273–2280, 2020.
- [9] R. Manojkumar, C. Kumar, S. Ganguly, and J. P. Catalão, "Net load forecast error compensation for peak shaving in a grid-connected PV storage system," *IEEE Trans. Power Syst.*, Early Access, 2023.
- [10] G. Pulazza, N. Zhang, C. Kang, and C. A. Nucci, "Transmission planning with battery-based energy storage transportation for power systems with high penetration of renewable energy," *IEEE Trans. Power Syst.*, vol. 36, no. 6, pp. 4928–4940, 2021.
- [11] Y. Chen, K.-W. Lao, D. Qi, H. Hui, S. Yang, Y. Yan, and Y. Zheng, "Distributed self-triggered control for frequency restoration and active power sharing in islanded microgrids," *IEEE Trans. Ind. Informat.*, vol. 19, no. 10, pp. 10635–10646, 2023.
- [12] R. Saavedra, A. Street, and J. M. Arroyo, "Day-ahead contingency-constrained unit commitment with co-optimized post-contingency transmission switching," *IEEE Trans. Power Syst.*, vol. 35, no. 6, pp. 4408–4420, 2020.
- [13] S. Yang, K.-W. Lao, Y. Chen, and H. Hui, "Resilient distributed control against false data injection attacks for demand response," *IEEE Trans. Power Syst.*, Early Access, 2023.
- [14] H. Hui, Y. Chen, S. Yang, H. Zhang, and T. Jiang, "Coordination control of distributed generators and load resources for frequency restoration in isolated urban microgrids," *Appl. Energy*, vol. 327, p. 120116, 2022.
- [15] R. Bhosale, R. Gupta, and V. Agarwal, "A novel control strategy to achieve soc balancing for batteries in a dc microgrid without droop control," *IEEE Trans. Ind. Appl.*, vol. 57, no. 4, pp. 4196–4206, 2021.