frontiers | Frontiers in Energy Research

TYPE Opinion
PUBLISHED 06 August 2024
DOI 10.3389/fenrg.2024.1448040

OPEN ACCESS

EDITED BY
Hui Hou,
Wuhan University of Technology, China

REVIEWED BY
Yonghui Liu,
Hong Kong Polytechnic University, Hong Kong SAR, China
Si-Zhe Chen,
Guangdong University of Technology, China
Junjun Xu,
Nanjing University of Posts and Telecommunications, China

*CORRESPONDENCE
Xiang Gao,
gaoxiang@szpu.edu.cn

RECEIVED 12 June 2024
ACCEPTED 23 July 2024
PUBLISHED 06 August 2024

CITATION
Ran H, Gao X, Wu Y, Zhang J and Jiang H (2024), A survey on emergency voltage control of active distribution networks with PV prosumers. *Front. Energy Res.* 12:1448040.
doi: 10.3389/fenrg.2024.1448040

A survey on emergency voltage control of active distribution networks with PV prosumers

Hanrui Ran[1], Xiang Gao[2]*, Yuheng Wu[1], Jin Zhang[3] and Hua Jiang[3]

[1]College of Electrical and Information Engineering, Hunan University, Changsha, China, [2]Industrial Training Centre, Shenzhen Polytechnic University, Shenzhen, China, [3]China Power Shentou Power Generation Co., Ltd., Shuozhou, China

KEYWORDS

active distribution networks, composite sensitivity analysis, coordinated emergency voltage control, distributed energy storage, photovoltaic

1 Introduction

Integrating large-scale distributed energy resources in the power grid has presented significant obstacles to the reliable and stable operation of active distribution networks (Murray et al., 2021). These challenges include voltage magnitude violation and frequency fluctuations. Large-scale grid integration of DERs replaces synchronous units with high resistance to interferences, which affects the voltage regulation capability (Hirase et al., 2022; Zhou et al., 2021). If the ADNs suffers severe failures, the operation of off-grid renewable energy stations may exacerbate voltage deterioration because the input power cannot support ADNs in maintaining normal voltage range (Huang et al., 2017; Ding and Baggu, 2018). Moreover, traditional voltage regulation equipment like transformer tapping terminal and capacitor banks may struggle to handle voltage magnitude violation under a high proportion of DERs due to their long control cycles (Islam et al., 2015; Srivastava et al., 2023). Recently, researchers have explored options for improving the voltage quality of ADNs, including configuring energy storage, reducing consumption of flexible loads and adjusting power factors of PV prosumers (Amroune et al., 2019; Chandak et al., 2019; Sun et al., 2022). However, the capacity of energy storage and PV prosumers to regulate voltage is limited. The voltage regulation characteristics of DERs vary widely. Distributed energy storage provides flexible operation across all four quadrants, with adjustable capabilities for active and reactive power. Distributed PV systems typically operate at their maximum power point to maximize the utilization of solar energy. Flexible loads are generally classified as interruptible or shiftable (Zhong et al., 2023). However, frequent changes in flexible load states should be minimized to ensure customer satisfaction. Considering the varying voltage regulation characteristics of DERs, coordinated voltage regulation can significantly improve the efficacy of voltage emergency management and expedite voltage recovery in the event of severe faults (Ye et al., 2018; Shahbazi and Karbalaei, 2020; Ma et al., 2021; Huang et al., 2022). Therefore, this study aims to offer valuable insights and discussions regarding emergency voltage control in ADNs with a significant proportion of DERs.

The main contributions of this work can be twofold as listed: (1) A composite sensitivity analysis for voltage prioritization control is proposed for determining the regulating capacity and range of each distributed resource to achieve effective voltage control in emergency situations; (2) a coordinated emergency voltage control strategy of ADNs has been formulated based on various voltage regulation characteristics to minimize voltage deviation and load shedding during emergencies, which enhances the operational reliability of ADNs and enables efficient accommodation of DERs.

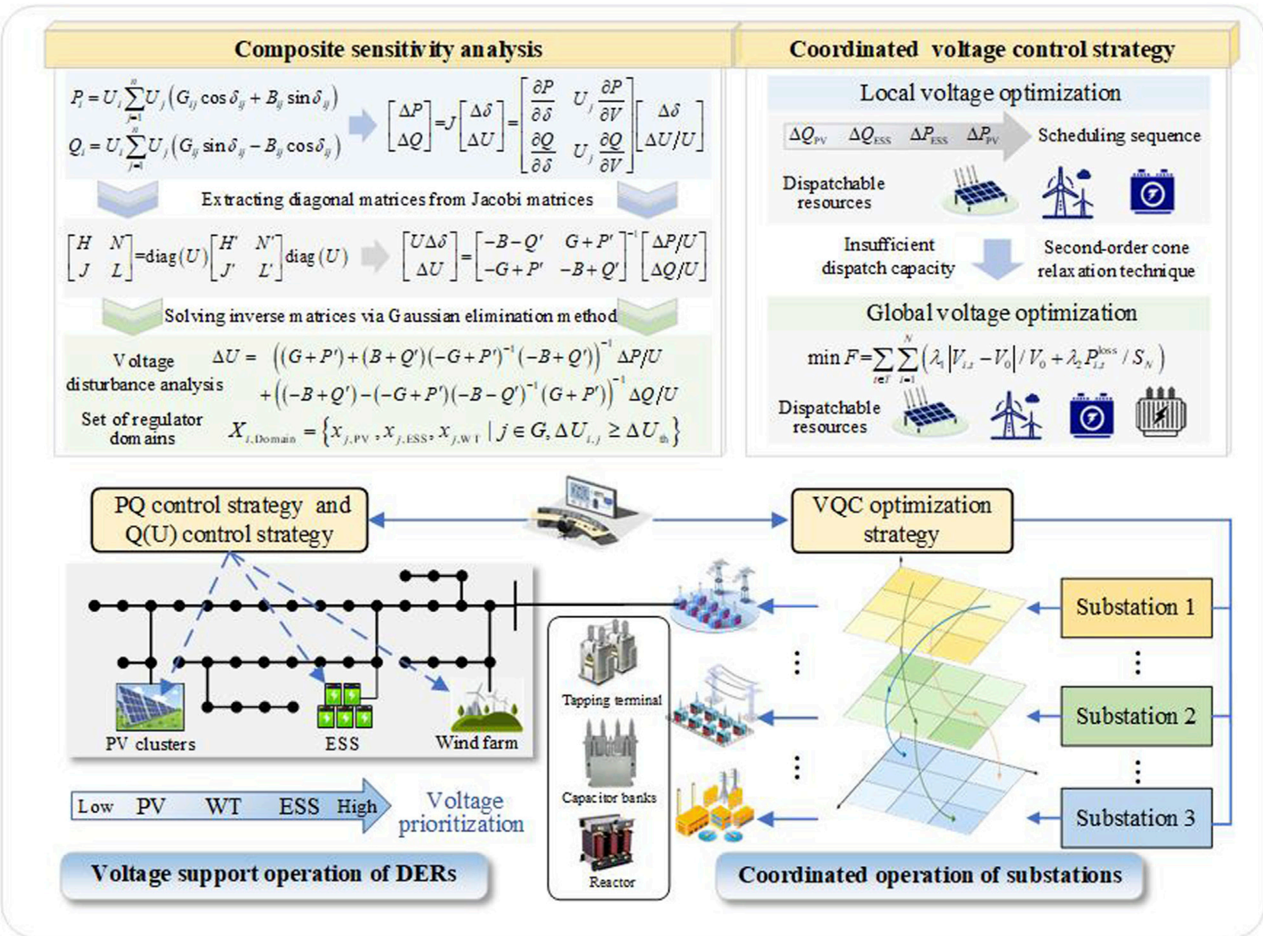

FIGURE 1
Composite sensitivity analysis and voltage control strategy for ADNs.

2 Composite sensitivity analysis for voltage prioritization control with PV prosumers

To effectively address voltage magnitude violation caused by ADNs faults and alleviate pressure on traditional voltage regulators, adjusting power output of distributed energy storage and reactive power output of PV prosumers is necessary to consider (Islam et al., 2015; Panasetsky and Voropai, 2009). However, since each distributed energy storage and PV prosumer has varying abilities to regulate the voltage at each node of the distribution network, a composite sensitivity analysis is necessary to determine the ability of distributed resources to adjust voltage on each node (SeokJu et al., 2019). A voltage prioritization control strategy has been proposed to coordinate the voltage regulation by DERs and traditional regulation equipment, as shown in Figure 1.

State variables such as voltage magnitude and phase angle can be altered by injecting power into energy storage or PV cluster. When the power of the energy storage or PV clusters increases, the power transmitted from the upper grid decreases, which reduces the voltage drop due to line losses and regulates the voltage of ADNs. The sensitivity analysis method calculates the voltage composite sensitivity matrix at each distribution network node by deriving the Newton-Raphson power flow calculation equation in polar coordinate form. The power equations expressed in polar coordinate form are presented as Equation 1:

$$\begin{cases} P_i = U_i \sum_{j=1}^{n} U_j \left(G_{ij} \cos \delta_{ij} + B_{ij} \sin \delta_{ij} \right) \\ Q_i = U_i \sum_{j=1}^{n} U_j \left(G_{ij} \sin \delta_{ij} - B_{ij} \cos \delta_{ij} \right) \end{cases} \tag{1}$$

where P_i, Q_i denotes the amount of active power and reactive power at node i; G_{ij}, B_{ij} denotes conductance and susceptance respectively; δ_{ij} denotes phase angle difference between two nodes. The Jacobi matrix expresses the connection between the increments of two variables in terms of partial derivatives. Consequently, the voltage composite sensitivity matrix can be derived by analyzing the Jacobi matrix. Meanwhile, the voltage complex sensitivity matrix can be derived by analyzing the power flow distribution under normal scenarios for reducing calculation time as the network topology of the distribution network has not changed and this processing still serves the practical requirements of the project for ensuring effective voltage prioritization control strategy. Equations 2, 3 illustrates the correlation between power variation on voltage and phase angle in ADN, and the voltage composite sensitivity matrix can be solved by following these steps:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = J\begin{bmatrix} \Delta\delta \\ \Delta U \end{bmatrix} = \begin{bmatrix} \frac{\partial P}{\partial \delta} & U_j\frac{\partial P}{\partial V} \\ \frac{\partial Q}{\partial \delta} & U_j\frac{\partial Q}{\partial V} \end{bmatrix}\begin{bmatrix} \Delta\delta \\ \Delta U/U \end{bmatrix} \tag{2}$$

$$\begin{cases} H_{ij} = \frac{\partial P_i}{\partial \delta_j} = U_iU_j\left(G_{ij}\sin\delta_{ij} - B_{ij}\cos\delta_{ij}\right) & H_{ii} = -U_i^2B_{ii} - Q_i \\ N_{ij} = U_j\frac{\partial P_i}{\partial U_j} = U_iU_j\left(G_{ij}\cos\delta_{ij} + B_{ij}\sin\delta_{ij}\right) & N_{ii} = U_i^2G_{ii} + P_i \\ J_{ij} = \frac{\partial Q_i}{\partial \delta_j} = -U_iU_j\left(G_{ij}\cos\delta_{ij} + B_{ij}\sin\delta_{ij}\right) & J_{ii} = -U_i^2G_{ii} + P_i \\ L_{ij} = U_j\frac{\partial Q_i}{\partial U_j} = U_iU_j\left(G_{ij}\sin\delta_{ij} - B_{ij}\cos\delta_{ij}\right) & L_{ii} = -U_i^2B_{ii} + Q_i \end{cases} \tag{3}$$

where ΔP, ΔQ denotes the amount of change in active power and reactive power; J refers to the Jacobi matrix. It can be inferred from these equations that the voltage sensitivity matrix, also known as the inverse matrix of the Jacobi matrix, serves as a means to validate the voltage regulating capability of each distributed energy storage and PV cluster at every node. It can be inferred from these equations that the voltage sensitivity matrix, also known as the inverse matrix of the Jacobi matrix, serves as a means to validate the voltage regulating capability of each distributed energy storage and PV cluster at every node. For a clearer representation of the active and reactive power's potential to regulate the voltage at each node, two voltage diagonal matrices are derived from the Jacobi matrix, and the process of deriving the voltage composite sensitivity matrix is shown in Eqs 4–7.

$$\begin{bmatrix} \Delta P_1 \\ \vdots \\ \Delta P_{n-1} \\ \Delta Q_1 \\ \vdots \\ \Delta Q_{n-1} \end{bmatrix} = \begin{bmatrix} U_1 & & & & & \\ & \ddots & & & & \\ & & U_{n-1} & & & \\ & & & U_1 & & \\ & & & & \ddots & \\ & & & & & U_{n-1} \end{bmatrix}\begin{bmatrix} H' & N' \\ J' & L' \end{bmatrix} \times \begin{bmatrix} U_1 & & & & & \\ & \ddots & & & & \\ & & U_{n-1} & & & \\ & & & U_1 & & \\ & & & & \ddots & \\ & & & & & U_{n-1} \end{bmatrix}\begin{bmatrix} \Delta\delta_1 \\ \vdots \\ \Delta\delta_{n-1} \\ \Delta U_1/U_1 \\ \vdots \\ \Delta U_{n-1}/U_{n-1} \end{bmatrix} \tag{4}$$

$$\begin{cases} H' = -B - Q' \\ N' = G + P' \\ J' = -G + P' \\ L' = -B + Q' \end{cases} \quad \cos\delta_{ij} \approx 1,\ \sin\delta_{ij} \approx 0 \tag{5}$$

$$\begin{bmatrix} U\Delta\delta \\ \Delta U \end{bmatrix} = \begin{bmatrix} -B - Q' & G + P' \\ -G + P' & -B + Q' \end{bmatrix}^{-1}\begin{bmatrix} \Delta P/U \\ \Delta Q/U \end{bmatrix} \tag{6}$$

$$\begin{aligned} \Delta U = &\left((G + P') + (B + Q')(-G + P')^{-1}(-B + Q')\right)^{-1}\Delta P/U \\ &+\left((-B + Q') - (-G + P')(-B - Q')^{-1}(G + P')\right)^{-1}\Delta Q/U \end{aligned} \tag{7}$$

where P', Q' denotes diagonal matrices and the main diagonal elements of the matrix are P_i/U_i^2 and Q_i/U_i^2 respectively. The voltage prioritization is determined by defining voltage change thresholds to identify flexibility resources that are more useful for voltage control as shown in Eq. 8.

$$\Delta U_{i,j} \geq \Delta U_{\text{th}} \tag{8}$$

where ΔU_{th} denotes voltage change thresholds. In order to regulate the node voltage, each distributed resource has a designated voltage regulation area based on the degree of impact from changes in PV and energy storage output. This ensures that each distributed storage and PV prosumer can effectively regulate the node voltage within their designated area while minimizing their impact on the node voltage outside of it. If the voltage of a node exceeds limit, the resources are scheduled based on voltage prioritization (Amjady and Esmaili, 2005). Suppose the regulating resource cannot return the voltage to the normal operating range. In that case, flexibility resources are dispatched in descending order of voltage variation to achieve coordinated voltage control during fault conditions in ADNs.

3 Coordinated emergency voltage control strategy of active distribution networks

In the event of voltage collapse caused by severe disturbance in ADNs, it is possible that scheduling distributed resources that heavily impact overrun node may not necessarily result in voltage recovery. In order to address this issue, a coordinated emergency voltage control model for ADNs has been proposed to minimize voltage deviation and load shedding under fault scenarios (Cao et al., 2024a), as illustrated in Figure 1. This paper's approach reduces the need for dispatching voltage control equipment and eases centralized control communication instead of implementing coordinated emergency voltage control directly. The objective function of emergency voltage control is formulated as Equation 9:

$$\min F = \sum_{t\in T}\sum_{i=1}^{N}\left(\lambda_1\frac{\left|V_{i,t} - V_0\right|}{V_0} + \lambda_2\frac{P_{i,t}^{\text{loss}}}{S_N}\right) \tag{9}$$

where λ_1 , λ_2 denote the weighting of the objectives; V_0 represents the rated voltage of the node; $V_{i,t}$ refers to actual operating voltage at time period t; $P_{i,t}^{\text{loss}}$ denotes the amount of load curtailment at time period t.

When optimizing operations, it is essential to consider the power balance of ADNs and the capacity and statues of DERs. The voltage deviation in the distribution network is affected by the active and reactive power flow, which can be controlled through optimal power flow (Panasetsky and Voropai, 2009). The main factors that affect the system power flow are the composite conductance and injected power of ADNs. PV clusters can regulate their own power output by changing the power factor, but the output cannot exceed the inverter capacity limit (Islam et al., 2015). To ensure the consumption ability of renewable energy resources, PV units normally operate at the maximum power point, which means the active output of PV prosumers is typically not dispatchable (Larsson et al., 2002). Therefore, ADNs need to be equipped with distributed energy storage with flexible regulation capabilities to regulate the power flow timely for avoiding the adverse effects of power fluctuations. Distributed energy storage has a four-quadrant power regulation capability, allowing it to adjust

TABLE 1 Division results of voltage regulation domain and comparison of assessment index.

Strategy	Voltage assessment index (%)				Resilience assessment index		Division results of voltage regulation domain
	Voltage eligibility rate	Voltage fluctuation	Voltage overrun	Voltage deviation	Amount of load shedding (MWh)	Scheduling counts	
Strategy 1	78.27	11.24	4.24	8.97	1.582	11	(2–6, 22–25) (7–10) (11–17) (18–21) (26–29) (30, 31, 32)
Strategy 2	98.48	7.04	0.04	3.08	0.647	107	
Strategy 3	97.88	7.12	0.12	3.29	0.467	56	

its active and reactive power output through charging and discharging (Xiong et al., 2020). However, distributed energy storage output should not exceed its inverter capacity limit, and must maintain a certain energy storage capacity (Tang et al., 2022). Additionally, there is a limit to the charging and discharging power of distributed energy storage.

When a fault strike causes the voltage of an active distribution network node exceed its limit, the distribution network coordinates the distributed resources in the regulation domain to address the local voltage regulation. Suppose the local voltage regulation is unsuccessful in restoring the voltage to the normal range. In that case, the distribution network then assesses the scheduling strategy of each voltage regulation resource and manages the status of remote-controlled switches to reconstruct network topology (Shi et al., 2021; Cao et al., 2024b). This is based on the coordinated emergency voltage control model, aiming to minimize voltage deviation and load shedding under the fault scenario.

In order to optimize emergency dispatch strategy for ADNs, several factors must be considered. The optimization variables of coordinated emergency voltage control strategy include diversified flexible resource regulation power source such as PV cluster and energy storage, transformer tap position and number of capacitor banks put into operation. The transformer tap position and number of capacitor banks are essential variables. While the proposed emergency dispatch model can be solved using second-order cone programming, the proposed emergency voltage control model for ADNs requires convex relaxation due to non-convexity resulting from secondary current constraints, etc. Therefore the constraints must be convexly relaxed and transformed into second-order cone constraints and linear constraints using the second order cone relaxation technique. The converted constraints are as shown in Equations 10–14:

$$\sum P^t_{i,j} - \sum P^t_{j,k} - \sum r_{i,j}\bar{I}^t_{i,j} = \left(P^t_{j,L} - P^t_{j,\mathrm{PV}} - P^t_{j,\mathrm{ESS}}\right)\ t \in [1, N_T] \tag{10}$$

$$\sum Q^t_{i,j} - \sum Q^t_{j,k} - \sum x_{i,j}\bar{I}^t_{i,j} = \left(Q^t_{j,L} - Q^t_{j,\mathrm{PV}} - Q^t_{j,\mathrm{ESS}} - Q^t_{j,\mathrm{CB}}\right)\ t \in [1, N_T] \tag{11}$$

$$\bar{U}^t_i - \bar{U}^t_j = 2\left(r_{i,j}P^t_{i,j} + x_{i,j}Q^t_{i,j}\right) - \left(r^2_{i,j} + x^2_{i,j}\right)\bar{I}^t_{i,j} \tag{12}$$

$$U^{\min}_i \le \bar{U}^t_i \le U^{\max}_i \tag{13}$$

$$\left\| \left[2P^t_{i,j}\ \ 2Q^t_{i,j}\ \ \bar{I}^t_{i,j} - \bar{U}^t_i \right]^{\mathrm{T}} \right\|_2 \le \bar{I}^t_{i,j} + \bar{U}^t_i \tag{14}$$

where $P^t_{j,L}$, $Q^t_{j,L}$ denotes the amount of load demand of node j at time period of t; $P^t_{j,\mathrm{PV}}$, $P^t_{j,\mathrm{ESS}}$, $Q^t_{j,\mathrm{PV}}$, $Q^t_{j,\mathrm{ESS}}$, $Q^t_{j,\mathrm{CB}}$ represents the power output of distributed power generation, energy storage and capacitor banks at time period of t, respectively; $P^t_{i,j}$, $Q^t_{i,j}$ refers to power output of transmission lines; $r_{i,j}$, $x_{i,j}$ is resistance and reactance of power transmission lines; $\bar{U}^t_i$, $\bar{I}^t_{i,j}$ represents squared values of voltage and current in ADNs.

4 Case studies

Simulations are conducted on modified IEEE 33-bus system to test the proposed emergency voltage control strategy with high PV prosumers penetration. The system includes four PV clusters and energy storage plants connected to ADNs. It is assumed that the capacity of each PV cluster and energy storage plant is 1.5 MW and 0.4 MW, respectively. The allowable maximum voltage deviation is set as 7%, with upper and lower voltage bounds at 1.07p.u. and 0.93p.u. The total output of the PV plants by 30 percent compared to the previous forecast caused by climate change, which lasted for almost an hour from the second moment. The total period and interval are set to 1 h and 5 min in the emergency scheduling, respectively.

The preeminence of the proposed strategy for emergency voltage control is verified by the comparative analysis of three strategies.

(1) Strategy 1: Traditional voltage regulating equipment, such as transformer tapping terminal and capacitor banks, participates in emergency voltage control based on a centralized optimization strategy.
(2) Strategy 2: DERs and traditional voltage regulating equipment, such as transformer tapping terminal and capacitor banks, participates in emergency voltage control based on a centralized optimization strategy.
(3) Strategy 3: DERs and traditional voltage regulating equipment, such as transformer tapping terminal and capacitor banks, participates in emergency voltage control based on the proposed strategy in this paper.

The division results of voltage regulation domain and the comparison of the voltage assessment index and resilience assessment index are shown in Table 1.

It can be found that the coordinated emergency voltage control strategy proposed in this paper improves voltage eligibility rate by

19.61% and reduces the average voltage deviation by 5.68% compared to Strategy 1. Meanwhile, the proposed strategy can satisfy the load demand to a great extent and reduces the amount of load shedding as the scheduling priority of local control. Compared to Strategy 2, the scheduling counts of voltage regulation equipment are reduced by 47.66%. The proposed strategy pays more attention to the local control of DERs in the regulating domain belonging to the overrun node than the centralized control, which improves the response rate of ADNs to emergency situation and the consumption of renewable energy resources.

5 Discussion and conclusions

A survey on emergency voltage control of ADNs with PV prosumers is presented in this paper. The following are the key findings of this study: 1) the proposed voltage prioritization control strategy analyzes a composite sensitivity matrix for determining voltage prioritization to alleviate the influence caused by emergency events. 2) A coordinated emergency voltage control strategy is proposed to reduce load shedding and voltage deviation; the voltage deviation can be alleviated by 5.68% and the scheduling counts of voltage regulation equipment are reduced by 47.66%. 3) Further research will focus on the strategy of network reconfiguration and the coordination of multiple repair teams during extreme weather, which will facilitate the resilient operations of ADNs.

Author contributions

HR: Writing–original draft, Writing–review and editing. XG: Conceptualization, Data curation, Writing–review and editing. YW: Visualization, Writing–review and editing. JZ: Formal Analysis, Writing–review and editing. HJ: Formal Analysis, Writing–review and editing.

Funding

The author(s) declare that financial support was received for the research, authorship, and/or publication of this article. This work was supported by Guangdong Basic and Applied Basic Research Foundation (2023A1515110105) and Scientific Research Startup Fund for Shenzhen High-Caliber Personnel of SZPT (6022310042k).

Conflict of interest

Authors JZ and HJ were employed by China Power Shentou Power Generation Co., Ltd.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

Amjady, N., and Esmaili, M. (2005). Application of a new sensitivity analysis framework for voltage contingency ranking. *IEEE Trans. Power Syst.* 20, 973–983. doi:10.1109/TPWRS.2005.846088

Amroune, M., Bouktir, T., and Musirin, I. (2019). Power system voltage instability risk mitigation via emergency demand response-based whale optimization algorithm. *Prot. Control Mod. Power Syst.* 4, 25. doi:10.1186/s41601-019-0142-4

Cao, Y., Zhou, B., Chung, C. Y., Wu, T., Ling, Z., and Shuai, Z. (2024a). A coordinated emergency response scheme for electricity and watershed networks considering spatio-temporal heterogeneity and volatility of rainstorm disasters. *IEEE Trans. Smart Grid* 15, 3528–3541. doi:10.1109/TSG.2024.3362344

Cao, Y., Zhou, B., Chung, C. Y., Zhou, K., Zhu, L., and Shuai, Z. (2024b). Resilience-oriented coordinated topology reconfiguration of electricity and drainage networks with distributed mobile emergency resources. *IEEE Trans. Smart Grid*, 1. doi:10.1109/TSG.2024.3419086

Chandak, S., Bhowmik, P., and Rout, P. K. (2019). Load shedding strategy coordinated with storage device and D-STATCOM to enhance the microgrid stability. *Prot. Control Mod. Power Syst.* 4, 22. doi:10.1186/s41601-019-0138-0

Ding, F., and Baggu, M. M. (2018). Coordinated use of smart inverters with legacy voltage regulating devices in distribution systems with high distributed PV penetration—increase CVR energy savings. *IEEE Trans. Smart Grid* 14, 1804–1813. doi:10.1109/TSG.2018.2857410

Hirase, Y., Takeda, T., and Ohuchi, K. (2022). Virtual synchronous generator based pole control in high-voltage DC transmission systems. *Energy Rep.* 8, 1073–1084. doi:10.1016/j.egyr.2021.11.050

Huang, G., Wang, J., Chen, C., Qi, J., and Guo, C. (2017). Integration of preventive and emergency responses for power grid resilience enhancement. *IEEE Trans. Power Syst.* 32, 4451–4463. doi:10.1109/TPWRS.2017.2685640

Huang, R., Chen, Y., Yin, T., Li, X., Li, A., Tan, J., et al. (2022). Accelerated derivative-free deep reinforcement learning for large-scale grid emergency voltage control. *IEEE Trans. Power Syst.* 37, 14–25. doi:10.1109/TPWRS.2021.3095179

Islam, S. R., Sutanto, D., and Muttaqi, K. M. (2015). Coordinated decentralized emergency voltage and reactive power control to prevent long-term voltage instability in a power system. *IEEE Trans. Power Syst.* 30, 2591–2603. doi:10.1109/TPWRS.2014.2369502

Larsson, M., Hill, D. J., and Olsson, G. (2002). Emergency voltage control using search and predictive control. *Int. J. Electr. Power & Energy Syst.* 24, 121–130. doi:10.1016/S0142-0615(01)00017-5

Ma, H., Liu, Z., Li, M., Wang, B., Si, Y., Yang, Y., et al. (2021). A two-stage optimal scheduling method for active distribution networks considering uncertainty risk. *Energy Rep.* 7, 4633–4641. doi:10.1016/j.egyr.2021.07.023

Murray, W., Adonis, M., and Raji, A. (2021). Voltage control in future electrical distribution networks. *Renew. Sustain. Energy Rev.* 146, 111100. doi:10.1016/j.rser.2021.111100

Panasetsky, D. A., and Voropai, N. I. (2009). A Multi-agent approach to coordination of different emergency control devices against voltage collapse. *IEEE Buchar. PowerTech.* doi:10.1109/PTC.2009.5281995

SeokJu, K., Jaewoo, K., Jung-Wook, P., and Seung-Mook, B. (2019). Reactive power management based on voltage sensitivity analysis of distribution system with high penetration of renewable energies. *Energies* 12, 1493. doi:10.3390/en12081493

Shahbazi, H., and Karbalaei, F. (2020). Decentralized voltage control of power systems using multi-agent systems. *J. Mod. Power Syst. Clean Energy* 8, 249–259. doi:10.35833/MPCE.2018.000628

Shi, Q., Li, F., Olama, M., Dong, J., Xue, Y., Starke, M., et al. (2021). Network reconfiguration and distributed energy resource scheduling for improved distribution system resilience. *Int. J. Electr. Power & Energy Syst.* 124, 106355. doi:10.1016/j.ijepes.2020.106355

Srivastava, P., Haider, R., Nair, V. J., Venkataramanan, V., Annaswamy, A. M., and Srivastava, A. K. (2023). Voltage regulation in distribution grids: a survey. *Annu. Rev. Control* 55, 165–181. doi:10.1016/j.arcontrol.2023.03.008

Sun, X., Qiu, J., Yi, Y., and Tao, Y. (2022). Cost-effective coordinated voltage control in active distribution networks with photovoltaics and mobile energy storage systems. *IEEE Trans. Sustain. Energy* 13, 501–513. doi:10.1109/TSTE.2021.3118404

Tang, L., Han, Y., Yang, P., Wang, C., and Zalhaf, A. S. (2022). A review of voltage sag control measures and equipment in power systems. *Energy Rep.* 8, 207–216. doi:10.1016/j.egyr.2022.05.158

Xiong, L., Liu, X., Zhao, C., and Zhuo, F. (2020). A fast and robust real-time detection algorithm of decaying DC transient and harmonic components in three-phase systems. *IEEE Trans. Power Electron.* 35, 3332–3336. doi:10.1109/TPEL.2019.2940891

Ye, X., Le, J., Liu, Y., Zhou, W., and Liu, K. (2018). A coordinated consistency voltage stability control method of active distribution grid. *J. Mod. Power Syst. Clean Energy* 6, 85–94. doi:10.1007/s40565-017-0294-z

Zhong, J., Li, Y., Wu, Y., Cao, Y., Li, Z., Peng, Y., et al. (2023). Optimal operation of energy hub: an integrated model combined distributionally robust optimization method with stackelberg game. *IEEE Trans. Sustain. Energy* 14, 1835–1848. doi:10.1109/TSTE.2023.3252519

Zhou, B., Zou, J., Chung, C. Y., Wang, H., Liu, N., Voropai, N., et al. (2021). Multi-microgrid energy management systems: architecture, communication, and scheduling strategies. *J. Mod. Power Syst. Clean Energy* 9, 463–476. doi:10.35833/MPCE.2019.000237