Power System Resiliency Studies under Renewable Energy Penetration: A Review

Mohammad Salimi
Department of Electrical and Computer Engineering
University of Saskatchewan
Saskatoon, SK, Canada
mohammad.salimi@usask.ca

Yuzhong Gong
Department of Electrical and Computer Engineering
University of Saskatchewan
Saskatoon, SK, Canada
y.z.gong@usask.ca

Shahabodin Afrasiabi
Department of Electrical and Computer Engineering
University of Saskatchewan
Saskatoon, SK, Canada
sh.afrasiabi@usask.ca

Xiaodong Liang
Department of Electrical and Computer Engineering
University of Saskatchewan
Saskatoon, SK, Canada
xil659@mail.usask.ca

Chi Yung Chung
Department of Electrical Engineering
The Hong Kong Polytechnic University
Hong Kong, China
c.y.chung@polyu.edu.hk

2022 IEEE Canadian Conference on Electrical and Computer Engineering (CCECE) | 978-1-6654-8432-9/22/$31.00 ©2022 IEEE | DOI: 10.1109/CCECE49351.2022.9918450

***Abstract*—High-impact low-probability (HILP) events can significantly threaten the resiliency of electric power grids. In the meantime, the utilization of renewable energy sources (RESs) has introduced serious challenges regarding their variability in the operation and planning of power systems. This paper provides a comprehensive review of power system resiliency studies for HILP events considering the integration of high penetration of RESs into power grids. The research reviewed can be classified into three levels, transmission systems, distribution systems, and microgrids (MGs). Findings in this review indicate both negative and positive impacts of RESs on grid resiliency, and several practices for mitigating those adverse consequences are advised in the paper.**

Keywords—Resiliency, power systems, renewable energy sources, wind power, photovoltaic

I. Introduction

In recent years, resilience has become one of the most significant aspects of electric power systems. With increasing dependence on electricity from various socioeconomic services, it is of crucial importance to guarantee the continuity of power supply in emergency conditions. The climate change-related events threaten the normal operating performance of power systems to a great extent, causing 30% of power outages from 1965 to 2012 [1]. The occurrence of such high-impact low-probability (HILP) events triggers the possibility of a lengthy power cutoff for consumers due to failures in the generation, transmission, and/or distribution levels. In the 2011 Great East Japan Earthquake and Tsunami, for instance, it took 99 days to fully restore power to customers [2]. This, in turn, leads to substantial economic losses for businesses that need an incessant power supply to function. For example, the 2012 Hurricane Sandy in the U.S. exceeded $60 billion in economic losses [3]. During the 2021 power crisis in Texas, the Electric Reliability Council of Texas (ERCOT) reported the loss of around 48.6% of its generation at the peak point as a result of extreme wind chills, which led to the bankruptcy of some energy firms [4]. Therefore, the cutting-edge research in the context of power system resilience has recently gained more interest among researchers.

Integration of renewable energy sources (RESs), mainly wind and solar photovoltaics (PVs), into the grid has dramatically increased in the past decades. From 2000 to 2015, the wind generation capacity has grown by more than 650% [5]. However, this large-scale integration has raised many technical issues regarding their uncertain behaviors. According to [6], the intermittency of wind energy is considered one of the major challenges to the development of wind power generation. Meteorological parameters also impact the output of solar PV generation units. The intermittent nature of RESs, along with the severe uncertainty of HILP events simultaneously threaten the sustainable and resilient operation/planning of power systems. Accordingly, much research has been carried out for resilience assessment and enhancement considering the role of RESs in today's power grids.

Although there are many reviews of resiliency in power systems, they mostly neglect to put focus on opportunities and challenges raised by the integration of RESs into the power grid. In this paper, first, RES-based resiliency-oriented studies in the literature are reviewed. Then, based on their findings, the pertinent challenges regarding the grid integration of RESs are identified. Finally, the expected methodologies to successfully deal with those challenges are introduced for future investigations. The structure of this paper is arranged as follows: Section II introduces the concept of resiliency in power systems; Section III covers the review and classification of resiliency studies considering the high penetration of RESs, and Section IV provides the conclusion and future research directions.

II. The Concept of Power System Resiliency

Although there are different explanations to define resilience in the context of power systems, it can be described as the ability of a power system to estimate the occurrence of HILP events, rapidly recover from those disruptive events, and learn from

This work was supported in part by the Natural Sciences and Engineering Research Council (NSERC) of Canada and the Saskatchewan Power Corporation (SaskPower).

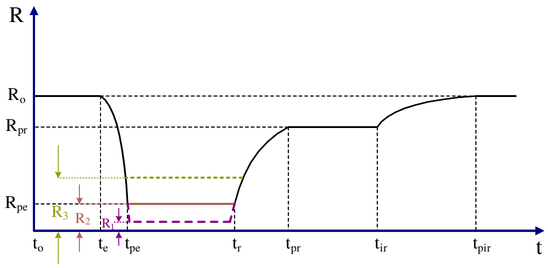

Fig. 1. Resistance feature in the resiliency curve [7].

such events to mitigate their adverse impacts in the future as a result of adaption in their operation and physical structure [7].

The resilience of a system as a function of time is depicted in Fig. 1 [7]. First, from t_o to t_e, the system is in its normal operation mode with the resiliency level R_o. A HILP event occurs at t_e and the resilience of the system degrades to R_{pe} until t_{pe}. The system remains in the degraded post-event state prior to the recovery of the system from t_r to t_{pr}, which leads to the elevation of the resilience to R_{pr}. After a short time, the system enters the infrastructure recovery phase, which is carried out from t_{ir} to t_{pir} and enhances the resiliency level to the pre-event level R_o. Therefore, the infrastructure recovery (t_{pir} -t_{ir}) usually takes longer compared to the initial recovery (t_{pr}-t_r). Based on Fig. 1, the per-unitized resiliency value of a system over a time span can generally be formulated as:

$$R = \frac{\int_{t_0}^{t_{pir}} R(t)dt}{\int_{t_0}^{t_{pir}} R_0 dt} \tag{1}$$

According to [8], the resilience framework consists of four key features: resistance, redundancy, resourcefulness, and rapidity:

- **Resistance**, which includes all preventive measures to minimize the post-event performance drop in the resiliency curve. Fig. 1 demonstrates the impact of the resistance feature on the resiliency level of the system. By increasing the resistance with the means of practices in Table 1, the resilience is also enhanced from R_1 to R_3. Please note that the least resistant system possesses the most degraded post-event state (R_1), while the system with the highest resistance level has the least degraded performance (R_3).

- **Redundancy** is described as the availability of diverse

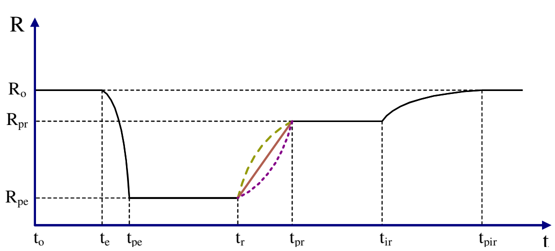

Fig. 2. Redundancy feature in the resiliency curve [7].

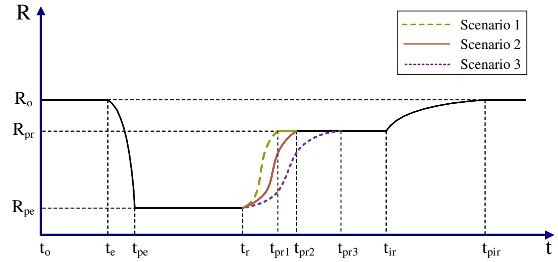

Fig. 3. Resourcefulness feature in the resiliency curve [7].

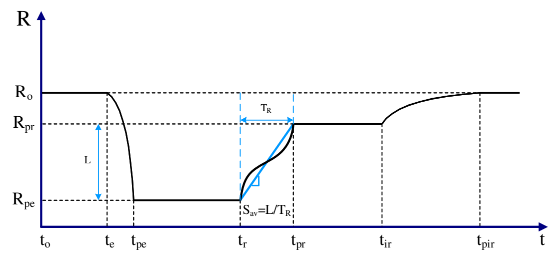

Fig. 4. Rapidity feature in the resiliency curve [7].

system assets as alternative recovery options in the post-event period. For instance, in Fig. 2, three different options can be chosen to boost the resilience of the system from R_{pe} to R_{pr}. The greater the number of the recovery options, e.g., redundancy practices in Table 1, the more the possibility of system restoration in emergencies.

- **Resourcefulness** is the third resiliency feature by which the effective management of resources during the recovery period is ensured. In Fig. 3, there is one recovery option with three different resourcefulness levels. Scenario 1 has the highest resourcefulness level as a result of the most effective management of system assets through implementing resourcefulness measures, as shown in Table 1. Therefore, the system recovery is accelerated. In contrast, Scenario 3 shows the least resourceful system with the slowest recovery trend.

- **Rapidity** is the ability to fast respond to and recover from HILP events. It can also be defined as the speed of recovery from the degraded post-event state to a suitable system performance level. Effective utilization of remotely controlled facilities, for instance, boosts the rapidity feature and, hence, the resilience. The average recovery speed S_{av} is demonstrated in Fig. 4, which is the division of loss L (R_{pr}-R_{pe}) to recovery time T_R (t_{pr}-t_r).

III. Resiliency with High Penetration Levels of RESs

A power system has several measures, resources, and preparations to ensure its resilient performance in extreme conditions. A list of such practices to enhance each of the aforementioned resiliency features is tabulated in Table I. These feature-specific measures impact the resiliency curve as discussed in Section II. Among the resiliency practices in power systems, the prominent role of fast-response distributed energy

TABLE I. FEATURE-SPECIFIC RESILIENCY PRACTICES IN POWER SYSTEMS

Resiliency Feature	Practices in Power Systems
Resistance	• Physical structure augmentation of lines/poles • Utilizing underground power lines in hurricane-prone areas • Exploiting overhead power lines in areas with a high potential for earthquakes • Using sectionalizing power line switches
Redundancy	• DERs for critical load pickup • Network topology reconfiguration using normally-open lines (tie lines) • Capability of load shedding with the priority of non-critical loads
Resourcefulness	• Investigating the possible post-event system states and preparation for corrective restoration measures • Training and preparation of repair crew • Utilizing advanced automation and protection facilities • Prioritizing the supply of load points in post events
Rapidity	• Exploiting remotely controlled facilities

resources (DERs) seems to be indisputable, especially when the upstream grid or its flow to the load points is lost. Due to the cost-effective and environmentally-friendly nature, the share of RESs in the generation mix is growing in modern grids. On the other hand, the integration of RESs into power systems has posed unprecedented challenges in their operation and planning. The intermittency of RESs can threaten the sustainable operation of power systems. However, their active cooperation and coordination with other assets ensure the enhanced resilient performance of the system in both operation and planning phases. Due to the complex uncertainty-driven nature of operation and planning problems entailing both the severity of HILP events and the variability of RESs, there is limited research addressing the raised concerns. In this paper, we have conducted a literature review of major research on the resilience of power systems with high penetration levels of RESs.

A. *Transmission-level studies*

The power system resilience can be investigated from the transmission-level perspective. As an operational study, Reference [9] has appraised the hurricane wind damage to power systems. The model was tested on a 2000-bus system in Texas, and it was concluded that with high penetration levels of RESs, there would be an increased loss of generation and restoration costs under hurricanes.

Other studies in transmission systems entail the planning phase [10]-[12]. As the transmission system planner is provided with limited budgets for resilience-promoting goals, it is crucial to optimally allocate those budgets among all existing planning tools. Therefore, a broad range of optimal practices from expansion planning and line hardening to siting and sizing of RESs, backup generation units, and energy storage systems (ESSs) can be done prior to the event. The resilience assessment of power grids against blackouts is investigated in [10]. With the progressive utilization of variable RESs (VRESs), the stress at the system level is increased, which may trigger blackouts. By minimizing the risk through the ORNL-PSERC-Alaska (OPA) model, the optimal location of VRESs and the proper estimation of ESSs is obtained. Therefore, the resilient operation can be realized if redundant RESs and storage units exist in the system. A resilience enhancement strategy against weather events is pursued in [11] to optimally coordinate wind farms with battery energy storage systems (BESSs). The model promotes the share of renewables in the supply of total demand under the renewable portfolio standard (RPS) policy. The failure probability of lines is also yielded by Monte Carlo Simulation (MCS).

Hardening transmission components against the impacts of natural disasters has become a more promising practice for resilience-oriented planning of grids in recent years. However, the variability of RESs may impose adverse impacts on the optimal implementation of this measure. Reference [12] has introduced a data-driven transmission hardening method to estimate the uncertainty sets associated with RESs. The results indicate that the hardening plans are less conservative than existing methods since this paper identifies the worst-case wind distribution. A summary of the transmission-level studies is provided in Table II.

B. *Distribution-level studies*

Various research has been conducted on the resilient operation of distribution systems incorporating RESs [13]-[24]. Reference [13] develops the probabilistic extreme event model, impact assessment model, and optimal damage minimization model for active distribution systems considering DERs. Besides ESSs and conventional distributed generators (DGs), PVs contributed to load restoration in an extreme event. Solution methodologies to enhance the resilience of power systems against wildfires have been introduced in [14]-[15]. The behavioral characteristics of wildfires have been integrated into an optimization model that allows distribution system operators to manage the system against progressive wildfires in the presence of RESs. It was concluded that by optimal coordination of all distribution-level energy resources, the destructive effects of such events could be remarkably reduced.

Critical load restoration in distribution systems can be followed using microgrid (MG) formation in the aftermath of a natural disaster [16]-[20]. A risk-limiting dispatch (RLD) approach has been used in [16] to account for the uncertainty of PVs and wind turbines. The proposed method updates the distributions associated with RESs based on their latest observation, which can improve resilience. References [17]-[18] adopt the capability of self-healing MGs for the resilience improvement of distribution systems. In the two-layer framework of [17], solving the distribution system restoration (DSR) problem outputs the optimal MG formation in the first layer and optimal energy management of DERs in the second layer. The framework proposed by [18] also emphasized the critical role of ESSs in cost reduction and reliable power provision through the self-healing networked MGs (NMGs).

TABLE II. TAXONOMY OF RES-BASED RESILIENCE-ORIENTED STUDIES IN TRANSMISSION SYSTEMS

Reference #	Type of the study	Type of RESs	Proposed method
[9]	Operation	PV and wind	MCS-based generation capacity loss and restoration cost evaluation
[10]	Planning	PV and wind	OPA-based risk assessment of VRES-integrated grid
[11]	Planning	Wind	Multistage MCS-based expansion co-planning of transmission lines, BESSs, and wind farms
[12]	Planning	Wind	Two-stage data-driven stochastic transmission hardening

An MG-aided restoration model is presented to enhance the resilience against floods and hurricanes in [19]. Microturbines, PVs, and ESSs are the energy procurement resources considered in this study. The results indicate the importance of the centralized approach in which MGs and the distribution system can cooperate to boost the restoration capability of the whole system. Besides maximizing critical load restoration through MGs, the expected voltage fluctuations during the restoration phase are minimized in [20] considering the utilization of renewable DGs.

Mobile energy sources are the newly introduced capability of distribution systems harnessed to battle against extremes [21]-[23]. The proposed model in [21] integrates the optimal routing and scheduling of mobile energy storage systems (MESSs), the dynamic topology reconfiguration of the distribution system, and the globally optimal stochastic uncertainty management of RESs using joint probabilistic constraints to ensure the maximum load pickup following HILP events. A new hierarchical resilience enhancement strategy in the post-event recovery phase is introduced, which captures the capability of emergency power supply vehicles (EPSs) to maintain the supply of critical loads [22]. PV and wind turbines are incorporated in the model yet neglect to focus on their intermittency. It was found that the system can still benefit from the energy provision of ESSs along with RESs in MGs. In addition to optimal pre-positioning of mobile emergency generators (MEGs), the proposed model in [23] aims at the optimal allocation of demand-side resources, including PV generators for enhanced load restoration against hurricanes.

Network topology reconfiguration is another operational tool for enhanced load restoration at the distribution level [21], [24]. An alternating direction method of multipliers (ADMM) is applied to the DSR problem in [24]. The developed two-stage framework provides a fully distributed topology reconfiguration and a fully distributed load restoration in the first and second stages, respectively. The effectiveness of inverter-based PVs and their load pickup contributions were demonstrated.

In the context of distribution system planning, the optimal implementation of generation expansion/allocation, energy storage allocation, network reconfiguration/partitioning, and line hardening has been studied [25]-[30]. A DG expansion planning model is developed in [25] to enhance the resilience of distribution systems using wind and solar generation during the fuel lifeline cutoff or damages to distribution circuits. As renewable generation becomes more prevalent in today's grids, their intermittency may not be handled without the inclusion of ESSs. Reference [26] proposes an optimized method to find the best ESS architecture when facing extreme weather events and considering a high ratio of roof-top PV systems. Authors in [27] try to averse the risks associated with the intermittency of renewable sources by coupling PVs with BESSs and providing planners with a list of optimal PV and BESS allocation schemes.

The network topology reconfiguration improves the resilience of planning decisions in distribution systems [28]-[29]. Reference [28] formulates an optimal distribution network partitioning (ODNP) problem against the disconnection of the main grid in catastrophic events. The problem addresses the uncertainty of the output of PVs but neglects to couple PV systems with ESSs. To enhance the resiliency against power line outages, the network reconfiguration can be coordinated with wind turbine allocation to make power flow interconnections between supply and load points in newly formed islands [29].

TABLE III. TAXONOMY OF RES-BASED RESILIENCE-ORIENTED STUDIES IN DISTRIBUTION SYSTEMS

Reference #	Type of study	Type of RESs	Handled uncertain sources	Proposed method
[13]	Operation	PV	RESs and HILP events	MCS-based impact assessment/restoration
[14]	Operation	PV and wind	RESs	Wildfire characterization-based optimal operation
[15]	Operation	PV and wind	RESs	Quadratic formulation for resource coordination
[16]	Operation	PV and wind	RESs	RLD-based restoration
[17]	Operation	PV and wind	-	Metaheuristics-based self-healing
[18]	Operation	PV and wind	RESs	Two-stage stochastic operation and self-healing
[19]	Operation	PV	RESs	Stochastic MG-aided service restoration
[20]	Operation	PV and wind	RESs	Chance-constrained service restoration
[21]	Operation	PV and wind	RESs	Stochastic routing and scheduling of MESSs
[22]	Operation	PV and wind	-	Three-level hierarchical service restoration
[23]	Operation	PV	HILP events	Two-stage Z-number-based robust recovery
[24]	Operation	PV	-	ADMM-based distributed service restoration
[25]	Planning	PV and wind	RESs	Multi-year, multi-criteria generation expansion
[26]	Planning	PV	-	OpenDSS-based grid optimal ESS architecture identification
[27]	Planning	PV	-	Hierarchy process-based PV and BESS allocation
[28]	Planning	PV	RESs	Chance-constrained ODNP
[29]	Planning	Wind	RESs and HILP events	Stochastic wind turbine allocation and network reconfiguration
[30]	Planning	N/A	RESs and HILP events	Robust line hardening

A robust optimization problem is presented in [30] to identify the optimal hardening designs along with optimal islanded multi-MGs under N-k contingencies. The model copes with the variability of renewable DGs (RDGs) through a scenario-based approach. The authors demonstrate the load pickup capability of RDGs. The taxonomy of the resilience-oriented studies in distribution systems is shown in Table III.

C. MG-based studies

Resilience-oriented studies involving MGs mostly cover their optimal operation and scheduling [31]-[36]. As a critical feature of power systems, MGs can enhance resiliency by mitigating curtailments during disruptions. Reference [31] proposes a resilient MG formation model considering input data uncertainties, including demand, the output of PVs, market price, and islanding duration, using the robust optimization technique. In [32], a stochastic linear programming framework for the optimal resilient scheduling of MGs is developed. The characterized uncertainties consist of wind data forecasting errors and contingency-driven uncertainties. The model outputs optimal schedules with lower curtailment costs.

Reference [33] has developed a two-stage approach for the optimal operation of MGs under HILP events. The model considers both the resiliency index and operation costs through a multi-objective optimization and aims to achieve an optimal balance between resiliency and economic indices by exploiting the potential of DERs and ESSs. The proactive resilience enhancement strategy adopted in [34] is carried out in two steps. First, the survivability of critical loads is ensured using the proactive scheduling of MGs. The second step determines the priority of battery charging and non-critical load pickup to consider the survivability of loads during islanded operation.

DC MGs can be connected to a distribution system to boost resilience [35]. The paper concluded that the occurrence time of the event highly impacts social behavior and, thus, resilience. The role of reactive power management in the resilience enhancement of NMGs by reducing the curtailment of active power levels has also been investigated in [36]. Table IV presents a list of conducted research on the resilience of MGs.

D. Other studies

The structural resilience of the American grid is analyzed in [37]. This paper suggests using RESs for decarbonization purposes. More specifically, besides RESs, other measures, including meshed lines and ESSs, are necessary. Furthermore, since there is no trade-off between resiliency and sustainability goals, they can be pursued at the same time. Although numerous research has investigated the resilience of supply at the system level, [38] adopts a consumer-centric approach. The stochastic model, which takes historical data of loads, PV, and wind for a household, indicated fewer resiliency costs associated with the distribution level when investing more at the customer level.

TABLE IV. TAXONOMY OF RES-BASED RESILIENCE-ORIENTED STUDIES IN MGS

Reference #	Type of the study	Type of RESs	Proposed method
[31]	Operation	PV	Robust Second Order Cone Power Flow-based MG scheduling
[32]	Operation	Wind	Two-stage stochastic MG scheduling
[33]	Operation	Wind	Two-stage stochastic MG scheduling
[34]	Operation	PV	Two-step proactive and survivability-oriented model of EMS
[35]	Operation	PV and wind	Multi-period two-stage stochastic normal and emergency scheduling
[36]	Operation	PV and wind	Two-stage stochastic emergency reactive power scheduling

IV. CONCLUSION AND FUTURE RESEARCH DIRECTION

Increasing penetration of renewable energy sources into modern power grids poses both favorable and adverse impacts on grids' operation and planning. Renewable-based DGs can promote resiliency by increasing a system's redundancy. In the aftermath of HILP events with the probable loss of the main transformer, the output of PVs and wind turbines can be an alternative energy resource to feed high-priority consumers. Resiliency can also be enhanced by diversifying available energy resources. A power system might possess several generation units with diverse sources as input, such as fuel in diesel generators or water in hydropower. The possible service interruption of these energy sources caused by extreme events can be mitigated by renewable energy sources without needing fuel to function.

Nevertheless, the high ratio of renewable energy sources brings significant challenges. The system operators cannot rely on their full capacities in emergencies since their forecasted generation may not be realized. Another contributing factor is the unknown occurrence time of HILP disasters. If the event happens at night, PVs cannot participate in load pickup. The output of wind turbines also depends on wind speed at that time. Moreover, if the HILP event occurs in peak demand, there would be a more serious challenge for operators to balance supply and demand. The event-specific effects of HILP events on RESs should also be considered. During hurricanes, for example, wind turbines are expected to be shut down. Accordingly, developing accurate data-driven forecast models of RESs and coupling their outputs with ESSs can be the most expected technologies in response to these challenging issues.

The application of risk-averse uncertainty-handling methods can be promising. Most studies have adopted probabilistic and robust techniques to deal with the uncertainty of HILP events. However, there is limited information about the behavior of past events and their impacts on system components, probabilistic methods may not accurately handle their uncertainty. On the other hand, the unknown severity degree of HILP events may raise some concerns regarding the application of robust optimization models, which need that information as input. Thus, it is of significance to employ a risk-averse uncertainty-modeling methodology, such as information gap decision theory (IGDT), which needs no uncertainty set of the extreme event as input. The successful application of IGDT in handling the uncertainty of extreme events has been demonstrated in [1]. Accordingly, as a software-based resiliency strategy, the authors suggest the implementation of a hybrid approach that integrates IGDT and data-driven methods to jointly handle the uncertainty of HILP events and RESs as future work.

REFERENCES

[1] M. Salimi, M. -A. Nasr, S. H. Hosseinian, G. B. Gharehpetian, and M. Shahidehpour, "Information gap decision theory-based active distribution system planning for resilience enhancement," *IEEE Trans. Smart Grid*, vol. 11, no. 5, pp. 4390-4402, Sep. 2020.

[2] M. Salimi, D. Faramarzi, S. H. Hosseinian, and G. B. Gharehpetian, "Replacement of natural gas with electricity to improve seismic service resilience: An application to domestic energy utilities in Iran," *Energy*, vol. 200, 117509, 2020.

[3] B. H. Strauss, P. M. Orton, K. Bittermann, M. K. Buchanan, D. M. Gilford, R. E. Kopp, S. Kulp, C. Massey, H. D. Moel, and S. Vinogradov, "Economic damages from Hurricane Sandy attributable to sea level rise caused by anthropogenic climate change," *Nat. Commun.*, 12, 2720, 2021.

[4] B. Magness, "Review of February 2021 Extreme Cold Weather Event – ERCOT Presentation," Electric Reliability Council of Texas, Feb. 2021.

[5] H. Samet, S. Ketabipoor, M. Afrasiabi, S. Afrasiabi, and M. Mohammadi, "Deep learning forecaster based controller for SVC: Wind farm flicker

mitigation," *IEEE Trans. Ind. Informat.*, to be published, doi: 10.1109/TII.2020.3025101.

[6] H. Samet, S. Ketabipour, S. Afrasiabi, M. Afrasiabi, and M. Mohammadi, "Prediction of wind farm reactive power fast variations by adaptive one-dimensional convolutional neural network," *Comput. Electr. Eng.*, vol. 96, no. 107480, Dec. 2021.

[7] M. Panteli and P. Mancarella, "The grid: Stronger, bigger, smarter?: Presenting a conceptual framework of power system resilience," *IEEE Power Energy Mag.*, vol. 13, no. 3, pp. 58-66, May/Jun. 2015.

[8] MCEER, "Engineering resilience solutions from earthquake engineering to extreme events," Multidisciplinary Center for Earthquake Engineering Research, USA, 2007.

[9] E. B. Watson and A. H. Etemadi, "Modeling electrical grid resilience under hurricane wind conditions with increased solar and wind power generation," *IEEE Trans. Power Syst.*, vol. 35, no. 2, pp. 929-937, Mar. 2020.

[10] B. A. Carreras, P. Colet, J. M. Reynolds-Barredo, and D. Gomila, "Assessing blackout risk with high penetration of variable renewable energies," *IEEE Access*, vol. 9, pp. 132663-132674, 2021.

[11] M. Moradi-Sepahvand, T. Amraee, and S. S. Gougheri, "Deep learning based hurricane resilient coplanning of transmission lines, battery energy storages, and wind farms," *IEEE Trans. Ind. Informat.*, vol. 18, no. 3, pp. 2120-2131, Mar. 2022.

[12] A. Bagheri, C. Zhao, F. Qiu, and J. Wang, "Resilient transmission hardening planning in a high renewable penetration era," *IEEE Trans. Power Syst.*, vol. 34, no. 2, pp. 873-882, Mar. 2019.

[13] P. Gautam, P. Piya, and R. Karki, "Resilience assessment of distribution systems integrated with distributed energy resources," *IEEE Trans. Sustain. Energy*, vol. 12, no. 1, pp. 338-348, Jan. 2021.

[14] M. Nazemi and P. Dehghanian, "Powering through wildfires: An integrated solution for enhanced safety and resilience in power grids," *IEEE Trans. Ind. Appl.*, Mar. 2022.

[15] M. Nazemi, P. Dehghanian, M. Alhazmi, and Y. Darestani, "Resilient operation of electric power distribution grids under progressive wildfires," *IEEE Trans. Ind. Appl.*, vol. 58, no. 2, pp. 1632-1643, Mar./Apr. 2022.

[16] Z. Wang, C. Shen, Y. Xu, F. Liu, X. Wu, and C. -C. Liu, "Risk-limiting load restoration for resilience enhancement with intermittent energy resources," *IEEE Trans. Smart Grid*, vol. 10, no. 3, pp. 2507-2522, May 2019.

[17] M. Zadsar, M. R. Haghifam, and S. M. M. Larimi, "Approach for self-healing resilient operation of active distribution network with microgrid," *IET Gener. Transm. Dis.*, vol. 11, no. 18, pp. 4633-4643, 2017.

[18] Z. Wang and J. Wang, "Self-Healing resilient distribution systems based on sectionalization into microgrids," *IEEE Trans. Power Syst.*, vol. 30, no. 6, pp. 3139-3149, Nov. 2015.

[19] A. Arif and Z. Wang, "Networked microgrids for service restoration in resilient distribution systems," *IET Gener. Transm. Distrib.*, vol. 11, no. 14, pp. 3612–3619, Sep. 2017.

[20] H. Gao, Y. Chen, Y. Xu, and C. C. Liu, "Resilience-oriented critical load restoration using microgrids in distribution systems," *IEEE Trans. Smart Grid*, vol. 7, no. 6, pp. 2837-2848, Nov. 2016.

[21] M. Nazemi, P. Dehghanian, X. Lu, and C. Chen, "Uncertainty-aware deployment of mobile energy storage systems for distribution grid resilience," *IEEE Trans. Smart Grid*, vol. 12, no. 4, pp. 3200-3214, Jul. 2021.

[22] L. Yang, Y. Zhao, C. Wang, P. Gao, and J. Hao, "Resilience-oriented hierarchical service restoration in distribution system considering microgrids," *IEEE Access*, vol. 7, pp. 152729–152743, 2019.

[23] X. Zhu, B. Zeng, Y. Li, and J. Liu, "Co-optimization of supply and demand resources for load restoration of distribution system under extreme weather," *IEEE Access*, vol. 9, pp. 122907-122923, 2021.

[24] R. R. Nejad and W. Sun, "Enhancing active distribution systems resilience by fully distributed self-healing strategy," *IEEE Trans. Smart Grid*, vol. 13, no. 2, pp. 1023-1034, Mar. 2022.

[25] H. Wang and T. Jin, "Prevention and survivability for power distribution resilience: A multi-criteria renewables expansion model," *IEEE Access*, vol. 8, pp. 88422-88433, 2020.

[26] J. Confrey, A. H. Etemadi, S. M. F. Stuban, and T. J. Eveleigh, "Energy storage systems architecture optimization for grid resilience with high penetration of distributed photovoltaic generation," *IEEE Syst. J.*, vol. 14, no. 1, pp. 1135-1146, Mar. 2020.

[27] T. R. B. Kushal and M. S. Illindala, "Decision support framework for resilience-oriented cost-effective distributed generation expansion in power systems," *IEEE Trans. Ind. Appl.*, vol. 57, no. 2, pp. 1246-1254, Mar./Apr. 2021.

[28] S. Biswas, M. K. Singh, and V. A. Centeno, "Chance-constrained optimal distribution network partitioning to enhance power grid resilience," *IEEE Access*, vol. 9, pp. 42169-42181, 2021.

[29] S. Nikkhah, K. Jalilpoor, E. Kianmehr, and G. B. Gharehpetian, "Optimal wind turbine allocation and network reconfiguration for enhancing resiliency of system after major faults caused by natural disaster considering uncertainty," *IET Renew. Power Gener.*, vol. 12, no. 12, pp. 1413–1423, Sep. 2018.

[30] X. Wang, Z. Li, M. Shahidehpour, and C. Jiang, "Robust line hardening strategies for improving the resilience of distribution systems with variable renewable resources," *IEEE Trans. Sustain. Energy*, vol. 10, no. 1, pp. 386–395, Jan. 2019.

[31] N. -M. Zografou-Barredo, C. Patsios, I. Sarantakos, P. Davison, S. L. Walker, and P. C. Taylor, "MicroGrid resilience-oriented scheduling: A robust MISOCP model," *IEEE Trans. Smart Grid*, vol. 12, no. 3, pp. 1867-1879, May 2021.

[32] A. Gholami, T. Shekari, F. Aminifar, and M. Shahidehpour, "Microgrid scheduling with uncertainty: The quest for resilience," *IEEE Trans. Smart Grid*, vol. 7, no. 6, pp. 2849-2858, Nov. 2016.

[33] A. Younesi, H. Shayeghi, P. Siano, A. Safari, and H. H. Alhelou, "Enhancing the resilience of operational microgrids through a two-stage scheduling strategy considering the impact of uncertainties," *IEEE Access*, vol. 9, pp. 18454-18464, 2021.

[34] L. K. Gan, A. Hussain, D. A. Howey, and H. Kim, "Limitations in energy management systems: A case study for resilient interconnected microgrids," *IEEE Trans. Smart Grid*, vol. 10, no. 5, pp. 5675-5685, Sep. 2019.

[35] M. E. Parast, M. H. Nazari, and S. H. Hosseinian, "Resilience improvement of distribution networks using a two-stage stochastic multi-objective programming via microgrids optimal performance," *IEEE Access*, vol. 9, pp. 102930-102952, 2021.

[36] A. Shaker, A. Safari, and M. Shahidehpour, "Reactive power management for networked microgrid resilience in extreme conditions," *IEEE Trans. Smart Grid*, vol. 12, no. 5, pp. 3940-3953, Sep. 2021.

[37] D. J. Thompson, W. C. H. Schoonenberg, and A. M. Farid, "A hetero-functional graph resilience analysis of the future American Electric Power System," *IEEE Access*, vol. 9, pp. 68837-68848, 2021.

[38] E. Chatterji, K. Anderson, and M. D. Bazilian, "Planning for a resilient home electricity supply system," *IEEE Access*, vol. 9, pp. 133774-133785, 2021.