International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 09 Issue: 07 | July - 2025 SJIF Rating: 8.586 ISSN: 2582-3930

A Systematic Review of Resilience Strategies in Active Distribution Networks

Mr. Pukhraj Soni[1], Mrs. Nanda R Mude[2],

[1]*M.Tech Scholar, Electrical Department, RSR RCET Bhilai, Chhattisgarh, India*
[2]*Assistant Professor, Electrical Department, RSR RCET Bhilai, Chhattisgarh, India*

---***---

Abstract - This paper presents a comprehensive review of microgrid architectures and the control strategies employed for various power converters. A microgrid can be described as an integrated system comprising distributed energy resources (DERs), energy storage units, and electrical loads. This innovative framework harnesses the capabilities of distributed generation technologies. In an AC microgrid, alternating current-based sources such as wind turbines are integrated along with DC-based sources like photovoltaic systems and fuel cells through inverters. Conversely, in a DC microgrid, AC sources must first be rectified to DC, while DC sources can be directly incorporated. To eliminate the inefficiencies caused by repetitive AC–DC–AC or DC–AC–DC conversions in standalone AC or DC microgrids, a hybrid microgrid structure is proposed. In this configuration, AC and DC sources are connected to their respective microgrids—AC sources to the AC network and DC sources to the DC network. An interlinking converter facilitates power exchange between the two networks, maintaining system balance by transferring energy based on load conditions. Finally, the paper also discusses various control strategies for these interlinking converters.

Key Words: Microgrid AC microgrid , DC microgrid , Hybrid microgrid , Distributed generator (DG).

1. INTRODUCTION

Active Distribution Networks (ADNs) have grown more dynamic and complicated as dispersed generation and renewable energy sources are increasingly integrated. But this change also leaves companies more susceptible to interruptions like equipment breakdowns, cyber-attacks, and natural catastrophes. In ADNs, resilience is the system's capacity to foresee, take in, adjust to, and quickly recover from such disruptions. The latest tactics and technological advancements made to improve ADN resilience are the main topic of this comprehensive study. It highlights the methods' efficacy, implementation difficulties, and potential avenues for further research by classifying them according to grid reconfiguration, microgrid integration, energy storage, data-driven fault detection, and cyber-physical security.

Distributed Generators (DG)

Distributed Generators (DGs) are increasingly vital across residential, commercial, and industrial sectors of modern power systems. They offer a decentralized alternative to traditional sources like coal, oil, gas, and hydropower. Typically ranging from 1 kW to 50 MW, DGs are small-scale units located closer to the load at the distribution level [1]. These systems are part of a broader category known as Distributed Energy Resources (DER), valued for their high efficiency, low emissions, and quiet operation. DGs often support a plug-and-play feature, allowing easy integration without modifying existing control infrastructure. Such systems serve as essential backup power sources in critical facilities like hospitals, academic institutions, and retail centers during grid outages. DG technologies include fuel cells, micro turbines, batteries, flywheels, and super capacitors. Renewable sources such as photovoltaic (PV) systems and wind turbines also contribute to distributed generation networks. The growing adoption of DGs supports energy reliability, sustainability, and grid resilience. Their modularity and flexibility make them integral to future smart grid applications.

Microgrid

A localized collection of dispersed energy supplies, loads, and energy storage devices with the potential to function in both islanding and grid-connected modes is known as a microgrid [2]. Due to its capacity to connect Distributed Generators (DG), microgrids are expanding quickly. Distributed generation (DG) has caused as many issues for the distribution system as it has resolved. The distribution system's stability and dependability are the primary issues with the DG.
Therefore, a microgrid is not created by connecting the dispersed generators to the distribution system. However, it needs to be properly managed using the right control techniques. As a result, the idea of local power generation and control in a distribution system also known as a microgrid was born. Microgrids have the potential to increase power system efficiency, lower costs, and improve performance [3].
Microgrids offer consumers a reliable and high-quality power supply with minimal interruptions. They enhance the efficiency, stability, and dependability of the overall power system. A key feature is their ability to seamlessly disconnect from or reconnect to the main grid during disturbances. During surplus generation, microgrids can feed excess power back into the utility grid. By optimizing the use of distributed generation; microgrids also contribute to lowering CO_2 emissions. They operate in two modes: islanded and grid-connected.
In islanded mode, the microgrid functions independently during grid failures while maintaining power quality for local loads. In grid-connected mode, it stays synchronized with the main grid, allowing two-way power exchange. Despite their advantages, microgrids face technical challenges such as voltage and frequency regulation, protection, and power quality during faults. This paper explores different microgrid architectures AC, DC, and hybrid AC–DC along with their operational principles and control strategies.

AC Microgrid

In AC microgrids, there are four major components that need to be coordinated, namely, control, i.e. active power, reactive power, harmonic, and unbalance components [4]. For the DC microgrids, there is only single component that has to be controlled i.e. DC power. These results in simplicity of the DC microgrid control system compared with the AC microgrid. Also power quality is main issue in AC microgrid compared to DC microgrid.

AC Microgrid Architecture

AC microgrid architecture is presented in Fig. 1. DC power from photovoltaic (PV) panel has to be converted into AC using DC–

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 09 Issue: 07 | July - 2025 SJIF Rating: 8.586 ISSN: 2582-3930

AC inverters before the connection [5]. To supply the power to DC loads, AC power has to be converted to DC. AC load can be directly connected with the AC bus. The embedded AC–DC converters are required for various appliances like computer, TV in home and office facilities to supply DC voltages. Wind power generation system is connected with the AC bus using converter that control active and reactive power. Main grid interconnection becomes easy because one has to simply match the grid and AC microgrid phase. The greatest benefit of an AC microgrid is that it can be easily stepped up for distribution over distance and again stepped down, near the load by using transformer with high efficiency [6]. Due to periodic zero voltage crossings, AC circuit protection schemes is benefited because fault current arc is extinguish by switching circuit breakers at zero crossing. The stable voltage can be obtained by controlling reactive power independently from real power. In grid connected mode, when main grid experiences an abnormal or faulty condition, then AC microgrid will isolate itself to protect the load within the microgrid. So, AC load within the AC microgrid will not be affected from main grid disturbance. Majority of the load in the present system is AC loads that can be directly interconnected with AC microgrid without any conversion.

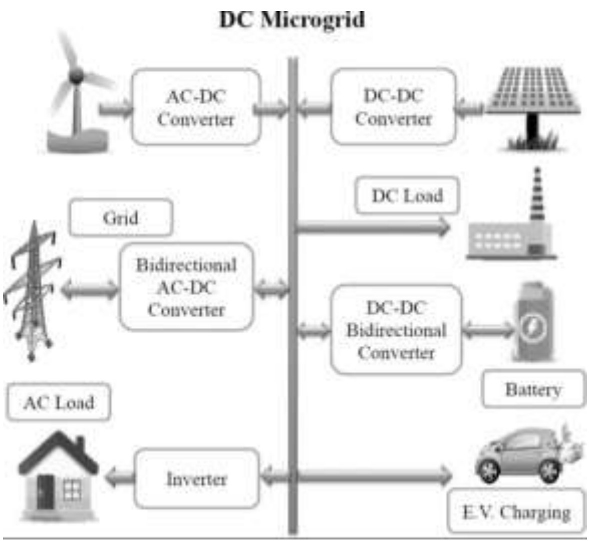

Fig. 1 AC microgrid architecture

There are certain drawbacks of AC microgrid, such as for DC loads like computers, battery charging, DC fluorescent lamps, AC power must be converted to DC. Due to this conversion efficiency is reduced. While supplying power to the DC load with the power electronics converters, it will inject harmonics in the main grid. Another drawback of AC microgrid is that integration of the DC renewable sources is not easy because PV output is DC and it must be converted to the AC using inverter.

DC Microgrid

Currently research in the DC microgrid is gaining momentum due to development of renewable DC power generation sources, fluorescent lighting and their inherent advantage for DC loads in commercial, industrial and residential applications. AC microgrids are already developed because of its various advantages that are listed earlier.

DC Microgrid Architecture

DC microgrid architecture is presented in Fig. 2. Two distributed generators are connected with the DC bus. For integration of wind turbine system with the DC microgrid AC–DC converter is required. Photovoltaic system is connected with DC microgrid via DC–DC boost converter.

DC–AC inverters are required for conventional AC load connections. In many countries people are using electric battery operated vehicles. Charging of Electric Vehicle (E.V.) battery requires DC voltage. So, in DC microgrid electrical vehicle will be easily charged. In hybrid electrical vehicle charging new concept is introduced, that is, to feed power back into the grid during the night time.

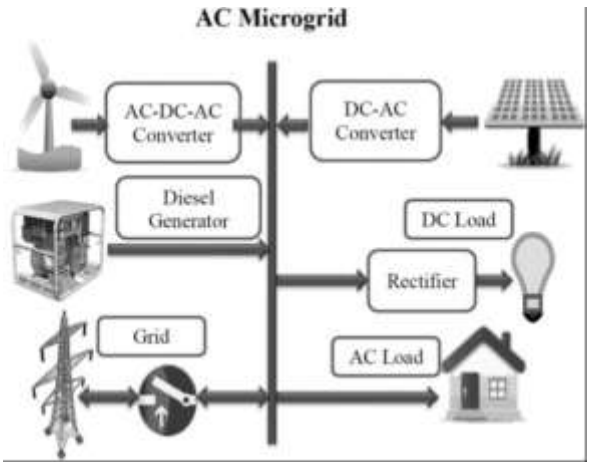

Fig. 2 DC microgrid architecture

This converter is used for the maximum power point tracking. All DC load can be directly connected with the DC bus without any conversion, which increases efficiency and reduces cost of the power electronics converters. However, So, needy people can use that power during that time while vehicle is in garage. But this concept requires two directional metering. These things are not discussed here in detail due to different objective of this paper. The main advantage of the DC system is that one can directly connect battery storage system for backup power supply. Backup storage system will provide power in the absence of any DG or during peak load period. It is also used to avoid supply interruptions in hospitals for critical equipments, in big office buildings for computers or in industries that required high quality power supply. Presently it is implemented with Uninterruptible Power Supply (UPS) with back to back conversion. A direct connection with DC microgrid eliminates power conversions and increases system efficiency.
There are certain benefits of DC microgrid like easy integration of renewable energy resources. DC microgrid battery storage will continuously supply power to load during any power outages in the AC main grid. Increasing dependence on lighting technologies like compact fluorescent lamps could accompany DC distribution [7]. The operating cost and power converter loss of DC system can be reduced, because there is only a single AC main grid connected inverter unit is required. Although in DC microgrid separate DC distribution line is required, the cost performance of DC houses, information centers and hospitals are satisfactory. There are also some drawbacks of DC microgrid like limited power distribution up to a small short line length (km). Most of the loads in present power system require AC power. So, only DC distribution is not possible in current power system structure. Compared to AC system voltage transformation DC system is less efficient. For integration of AC distributed generators rectifier is required to convert AC power to DC power. From the literature survey of microgrid architectures it can be concluded that individual AC or DC microgrid requires multiple reverse conversions for integration of various loads and

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 09 Issue: 07 | July - 2025 SJIF Rating: 8.586 ISSN: 2582-3930

renewable energy resources. This increases losses and complexity of the whole power system. The cost of the equipment is also increased due to the embedded AC/DC and DC/AC converters. A Hybrid AC–DC microgrid concept is introduced in the work of Wang et al. [8]. That avoids multiple reverse conversions in an individual Fig. 2 DC microgrid architecture AC–DC microgrid.

Hybrid AC–DC Microgrid

Hybrid AC–DC Microgrid Architecture Development of hybrid microgrid is initiated after reopening of discussion cum competition between George Westinghouse and Thomas Edison, which is related to merits of AC and DC distribution systems. Relative merits of both AC and DC microgrid architecture are already discussed in this paper. Hybrid microgrid is the concept of combining both AC and DC microgrid architectures. So, hybrid microgrid is having advantages of both the individual microgrids. A typical hybrid AC–DC microgrid is shown in Fig. 3. There are AC and DC microgrids that are connected together through bidirectional AC–DC (Interlinking) converters. All DC power generators like photovoltaic (PV) panels and fuel cell (FC) are connected to DC microgrid through DC–DC boost converters. DC loads such as electric vehicles, fluorescent lamps are connected to DC microgrid through DC–DC buck converters. Energy storages devices are connected to DC microgrid through bidirectional DC–DC converters. AC microgrid is usually tied up with utility grid. AC power generators such as wind turbine generators and small diesel generators are connected to AC network. AC loads such as AC motors are connected to AC microgrid.

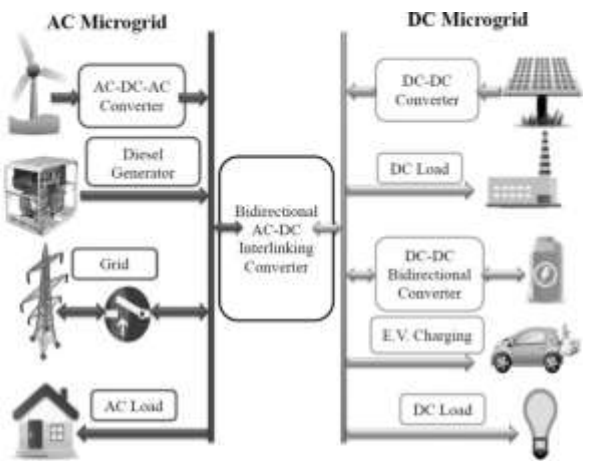

Fig. 3 Hybrid AC–DC microgrid architecture

Voltage level of the AC grid is 230 or 400 V (L–L) rms. There are still no standard voltage levels for DC microgrid. When AC microgrid is overloaded at that time power will flow from the DC microgrid to AC microgrid. In this case main converter will operate as inverter. When DC microgrid is overloaded then the main converter will operate as a rectifier and power will flow from AC microgrid to the DC microgrid.

Main function of the interlinking converter (IC) is smooth power transfer between microgrids. When both microgrids are overloaded during that time grid will supply power. When both microgrids having surplus power generation then that surplus power will be fed into main grid. Hybrid AC–DC microgrid reduces process of multiple AC– DC–AC or DC–AC–DC conversions in an individual AC or DC microgrid [24] and provide high quality, uninterruptable and reliable energy supply to critical loads. It also facilitates the connections of various renewable AC and DC sources and loads to the power system.

Frequency Droop Control Technique

Frequency droop control is based on the principle that as the real power output of a generator increases, its frequency decreases. This allows generators to proportionally share the active power demand.

The frequency droop control law can be expressed by the following equation:

$f = f_0 - K_p(P - P_0)$…………………(1)

Where:

f : Output frequency of the DG unit

f_0 : Nominal system frequency (e.g., 50 Hz or 60 Hz)

P : Measured real power output

P_0 : Nominal real power output

K_p : Frequency droop coefficient Frequency

The primary purpose of frequency droop control is to enable decentralized load sharing among multiple distributed energy resources (DERs) in a microgrid. It helps to Ensure proportional power sharing, Eliminate the need for fast communication links, Provide grid-forming capability in islanded mode, Enhance stability and scalability of the microgrid.

Droop Control Droop control technique is used to control power sharing of two parallel sources [26]. In frequency droop control scheme two droop control equations are used to determine its reference frequency f and voltage amplitude V from its measured active power P and reactive power Q values, respectively.

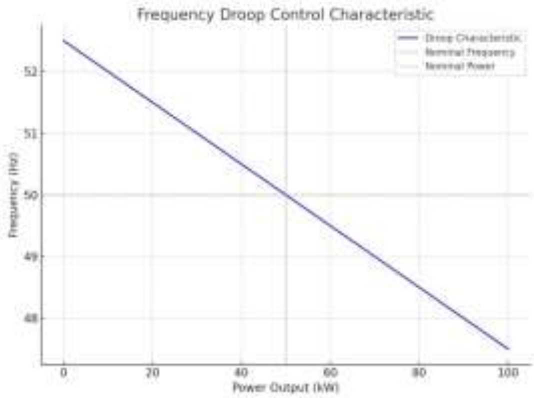

Fig. 4 Frequency versus active power droop characteristics

A. Ghosh et al., 2023 this paper presents a dynamic reconfiguration algorithm using graph theory to enhance post-fault resilience in ADNs [9]. It integrates distributed generation (DG) and switchable network topology to restore maximum load. Simulation results show that the proposed strategy significantly improves resilience indices under N-1 contingencies. Load recovery rate and fault isolation time are used as key performance indicators. The study emphasizes real-time control integration for improved response speed. It concludes that proactive switching coupled with DG coordination enhances grid survivability.

H. Wang et al., 2022 the paper analyzes microgrid islanding and re-connection schemes for ADN resilience under severe disturbances [10]. It proposes a two-stage control strategy involving fast isolation and gradual load restoration. Case studies with renewable energy penetration highlight improved voltage/frequency regulation post-disturbance. An adaptive droop mechanism is used for balanced load sharing during islanded operation. It integrates communication constraints to ensure real-world applicability. The results affirm the importance of multi-layer control in active distribution systems.

S. Liu et al., 2021 this research proposes a machine learning-based fault detection and isolation system for real-time resilience [11]. Historical SCADA and PMU data are used to train neural networks for fault classification. The system achieves high accuracy and fast detection across various fault types and topologies. It enables pre-emptive load transfer actions using DERs and switches. The authors suggest integrating AI with edge computing for scalable deployment. It proves that data-driven techniques enhance visibility and reactivity in resilient networks.

Y. Chen et al., 2021, A planning model is proposed incorporating resilience, cost, and renewable integration metrics [12]. It optimizes DER locations, energy storage sizing, and network upgrades under extreme event scenarios. NSGA-II algorithm is used to handle multi-objective trade-offs. Simulation on IEEE-33 bus system shows improved resilience indices and energy efficiency. The approach provides planners a tool to balance investment and resilience. The paper validates that resilience must be embedded in long-term ADN planning.

R. Zhang et al., 2020, the paper presents a self-healing architecture using intelligent electronic devices and rule-based control [13]. It models protection coordination and automated reclosing strategies to minimize outage durations. Restoration time is reduced using location-based fault isolation and dynamic load management. IEC 61850 communication protocol is utilized for automation. Simulation on real utility data validates the fast restoration capabilities. It concludes that distributed automation enables resilient and adaptive operation.

F. Naseri et al., 2020, the paper explores the impact of cyber threats on the resilience of ADNs. A hybrid model evaluates physical faults and communication disruptions simultaneously [14]. Mitigation strategies include data redundancy, intrusion detection, and decentralized control. Case studies show how coordinated cyber-attacks degrade fault detection and restoration response. A resilience index is proposed combining physical and cyber failure recovery metrics. It stresses the need for integrated cyber-physical security in resilient ADN design.

K. Singh et al., 2019, this paper examines how BESS (Battery Energy Storage Systems) can support ADN resilience. It models energy dispatch during faults and outages using predictive control [15]. Resilience metrics such as unserved energy and load recovery time are minimized. Multi-agent control is used to coordinate multiple BESS units. Case studies demonstrate effective voltage support and black-start capability. It emphasizes that distributed storage is crucial in forming resilient grid segments.

T. Morstyn et al., 2018, A decentralized energy market is proposed to enhance flexibility and resilience in ADNs [16]. Local prosumers trade energy based on demand and availability, reducing dependence on central grid. Blockchain-based contracts ensure secure and autonomous operation. During grid stress events, the system can adapt through price signals. Simulations show enhanced recovery and load balancing after faults. It introduces market-driven resilience as a novel concept.

D. Yang et al., 2017, the paper investigates the deployment of mobile generators and battery trucks after natural disasters [17]. An optimization model determines optimal placement and routing of mobile resources. It supports load prioritization (critical loads first) in a damaged distribution network. Case studies from hurricane-hit regions validate the approach. It supports resilience-as-a-service using temporary energy assets. The model shows mobile resources as effective interim resilience enhancers.

M. Panteli et al., 2016, this foundational paper proposes resilience definitions, metrics, and evaluation frameworks [18]. It differentiates resilience from reliability and focuses on pre-event, during-event, and post-event phases. Case studies include distributed grids subjected to storms and cyber threats. A resilience trapezoid is introduced to visualize system behavior over time. The authors suggest embedding resilience planning in all stages of grid design. It serves as a base for all subsequent research in resilient ADNs.

3. CONCLUSIONS

The reviewed literature shows that resilience in Active Distribution Networks (ADNs) is a multidimensional goal involving control strategies, network planning, cyber-security, and DER integration. Techniques such as reconfiguration, energy storage, microgrids, AI-based fault detection, and decentralized trading enhance the ability of ADNs to withstand and recover from both natural and cyber-induced disruptions.It is evident that future resilient grids must not only adapt to faults but also proactively prevent cascading failures through smart coordination. Furthermore, embedding resilience in planning, rather than treating it as a post-operational feature, is a recurring recommendation across all studies. The main barrier to expand DC microgrid is lesser amount of DC loads in the present power system. Hybrid microgrid comes out to be a great solution with advantages of both AC and DC microgrid. Hybrid microgrid architecture reduces multiple reverse conversions that occur in an individual AC and DC microgrid. In hybrid microgrid development main focus of researchers is on the control strategy of interlinking converter for better power sharing between the two microgrids.

REFERENCES

1. Adefarati, Temitope, and Ramesh C. Bansal. "Integration of renewable distributed generators into the distribution system: a review." IET Renewable Power Generation 10.7 (2016): 873-884.
2. Wang, Zhaoyu, Bokan Chen, and Jianhui Wang. "Decentralized energy management system for networked microgrids in grid-connected and islanded modes." IEEE Transactions on Smart Grid 7.2 (2015): 1097-1105.
3. Yoldaş, Yeliz, et al. "Enhancing smart grid with microgrids: Challenges and opportunities." Renewable and Sustainable Energy Reviews 72 (2017): 205-214.
4. Rodrigo, P. M., Ramiro Velázquez, and Eduardo F. Fernández. "DC/AC conversion efficiency of grid-connected photovoltaic inverters in central Mexico." Solar Energy 139 (2016): 650-665.
5. Sarangi, Swetalina, Binod Kumar Sahu, and Pravat Kumar Rout. "Distributed generation hybrid AC/DC microgrid protection: A critical review on issues, strategies, and future directions." International Journal of Energy Research 44.5 (2020): 3347-3364.
6. Watson, Neville R., Tasman L. Scott, and Stephen JJ Hirsch. "Implications for distribution networks of high penetration of compact fluorescent lamps." IEEE transactions on power delivery 24.3 (2009): 1521-1528.
7. Singh, Jaswant, et al. "Recent control techniques and management of AC microgrids: A critical review on issues, strategies, and future trends." International Transactions on Electrical Energy Systems 31.11 (2021): e13035.
8. Liu, Xiong, Peng Wang, and Poh Chiang Loh. "A hybrid AC/DC microgrid and its coordination control." IEEE Transactions on smart grid 2.2 (2011): 278-286.
9. A Ghosh, S. Chanda and A. K. Srivastava, "Resilience-Oriented Grid Reconfiguration in Active Distribution Networks," IEEE Transactions on Smart Grid, vol. 14, no. 2, pp. 987–996, Mar. 2023.

10. H. Wang, Y. He and J. Zhao, "Coordinated Microgrid Control for Enhancing ADN Resilience: A Review," Renewable and Sustainable Energy Reviews, vol. 160, p. 112276, Mar. 2022.
11. S. Liu, R. Wang, Q. Hu and Y. Liu, "Data-Driven Fault Detection for Resilient Distribution Grids," in Proc. IEEE Power & Energy Society General Meeting, Washington, DC, USA, pp. 1–5, 2021.
12. Y. Chen, F. Li, X. Liu and B. Wang, "Multi-Objective Planning of Active Distribution Networks Considering Resilience Metrics," Electric Power Systems Research, vol. 196, p. 107220, Apr. 2021.
13. R. Zhang, M. Yu and T. Jin, "A Self-Healing Framework for Active Distribution Networks Using Intelligent Electronic Devices," IEEE Access, vol. 8, pp. 155039–155051, Aug. 2020.
14. F. Naseri, M. Fotuhi-Firuzabad and H. Lesani, "Resilience Assessment of Cyber-Physical Distribution Networks under Coordinated Attacks," Journal of Modern Power Systems and Clean Energy, vol. 8, no. 6, pp. 1174–1183, Nov. 2020.
15. K. Singh, A. Tiwari and R. Gupta, "Enhancing Resilience in Active Distribution Networks Using Distributed Energy Storage," IEEE Transactions on Smart Grid, vol. 10, no. 4, pp. 4049–4058, Jul. 2019.
16. T. Morstyn, A. Teytelboym and M. D. McCulloch, "Peer-to-Peer Energy Trading for Resilient Local Energy Systems," Nature Energy, vol. 3, pp. 94–102, Jan. 2018.
17. D. Yang, Y. Xu and Z. Y. Dong, "Post-Disaster Restoration Planning With Mobile Emergency Resources in Active Distribution Networks," Applied Energy, vol. 210, pp. 101–111, Jan. 2018.
18. M. Panteli, D. N. Trakas, P. Mancarella and N. D. Hatziargyriou, "Power System Resilience: Definition, Challenges and Mitigation Strategies," IEEE Transactions on Power Systems, vol. 32, no. 6, pp. 4290–4299, Nov. 2017.