Exploring the Impact of Resilience of Hybrid Micro-Grid against Extreme Weather conditions: A review

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ABSTRACT

Hybrid microgrids are a vital element in the quest to meet the ever-increasing power demands in the future while also providing a means for generating energy in an environmentally friendly manner that aligns with sustainable practices. However, the journey toward establishing, operating, and effectively utilizing these innovative hybrid microgrids has various challenges. These challenges include the complexities of Optimization Control, the integration of Energy Storage systems, the need for economic viability, the considerations for Scalability and Replicability, the imperative of cybersecurity, the nuances of Grid Interpolarity, and the necessity for social Acceptance. In addition, it is vital to conduct thorough Environmental Impact Assessments, employ sophisticated Data Analytics, and leverage advanced Machine Learning Techniques, all while ensuring the system's Resilience against the increasingly severe and unpredictable extreme Weather Conditions that can arise. Among the myriad of issues listed above, this paper takes a focused approach by reviewing the vital aspect of Resilience within Hybrid Micro Grids, particularly concerning their capacity to withstand and adapt to extreme Weather Conditions, utilizing a combination of definitions, methodologies, and a detailed exploration of various influencing factors. Through this comprehensive examination, the paper seeks to illuminate the intricacies of fortifying Hybrid Micro Grids against environmental adversities, thereby enhancing their overall efficacy and reliability in the face of unpredictable challenges. Ultimately, the findings aim to contribute valuable insights that can assist in the advancement of Hybrid Micro Grids, ensuring they not only meet future energy demands but do so in a manner that is both sustainable and resilient.

Keywords: Hybrid Microgrid, Traditional Grid, Resilience, Economic Viability, Weather Conditions

INTRODUCTION

The global energy sector is experiencing a significant transformation driven by the urgent necessity to cut greenhouse gas emissions linked to climate change drastically, enhance energy security against potential disruptions, and improve access to reliable and sustainable energy solutions for everyone. In this scenario, hybrid microgrids have surfaced as an up-and-coming and innovative solution, skilfully combining various energy sources, including solar, wind, diesel generators, and cutting-edge energy storage technologies, to tackle these critical challenges effectively.

These decentralized energy systems are designed to function smoothly in grid-connected and off-grid modes, providing greater resilience, adaptability, and efficiency than traditional grid systems that often struggle under various pressures.

Hybrid microgrids utilize a strategic blend of renewable energy sources alongside traditional energy options to ensure a stable and environmentally friendly electricity supply that meets the needs of contemporary society. For example, effectively harnessing solar and wind energy is vital for significantly reducing reliance on fossil fuels, which helps decrease harmful carbon emissions that contribute to air pollution. Meanwhile, diesel generators or other conventional power sources can be dependable backups when renewable generation is insufficient due to intermittent conditions. Additionally, incorporating advanced energy storage systems not only boosts the stability and reliability of these microgrids but also effectively addresses the inherent fluctuations and variability associated with renewable energy sources, ensuring a consistent energy supply for users.

Despite their considerable promise, hybrid microgrids encounter numerous significant challenges that impede their broader adoption and implementation in the energy sector. These challenges include complex optimization issues requiring sophisticated algorithms, system control and stability concerns that call for innovative solutions, cybersecurity threats that jeopardize the integrity of energy systems, uncertainties regarding the economic feasibility of such projects, and social acceptance barriers that must be overcome to gain public support.

Tackling these multifaceted challenges is essential for enhancing the operational effectiveness of hybrid microgrids and ensuring they meet the diverse needs and expectations of various stakeholders involved in energy production and consumption.

This research initiative aims to identify and thoroughly investigate critical research gaps within the realm of hybrid microgrids, exploring various aspects such as optimizing energy resource allocation, addressing the complex challenges of system control and stability, integrating energy storage solutions, tackling pressing cybersecurity issues, examining economic viability and potential business models, scalability and replicability concerns, factors influencing public acceptance, comprehensive evaluations of environmental impacts, and the resilience of these systems in extreme weather conditions. By carefully analyzing these critical topics, this study seeks to contribute to the ongoing development of hybrid microgrid technology and promote its integration into modern energy frameworks, ultimately paving the way for a more sustainable and resilient future in energy production and consumption.

Comparison Of Hybrid Microgrid With Conventional Grid

Hybrid microgrids, which integrate renewable energy sources with traditional power systems, offer enhanced resilience against extreme weather events compared to conventional grid systems. This resilience is crucial for maintaining energy security, especially amid increasing climate-related disruptions. Hybrid microgrids provide several advantages, including improved reliability, flexibility, and the ability to operate independently from the primary grid during outages. These features make them a promising solution for enhancing energy security in vulnerable regions.

A. Resilience of Hybrid Microgrids

- Distributed Energy Resources (DERs): Hybrid microgrids leverage DERs, such as solar and wind energy, which can be strategically deployed to enhance the resilience of power distribution systems. These resources allow for flexible load restoration strategies, which are crucial during extreme weather events when traditional grid systems may fail [3].
- Islanding Capabilities: One of the critical features of hybrid microgrids is their ability to operate in island mode, meaning they can disconnect from the main grid and continue to supply power independently. This capability is vital during grid failures caused by extreme weather, ensuring continuous power supply to critical loads [1].
- Advanced Control Systems: Hybrid microgrids often incorporate advanced control systems and optimization algorithms, such as the prairie dog optimization algorithm, which enhance their ability to manage power quality issues and maintain stable operations during disturbances [8].

B. Implications for Energy Security

- Reduced Transmission Losses: By generating and distributing power locally, hybrid microgrids reduce transmission losses, common in traditional grid systems. This efficiency provides a more reliable power supply in remote or isolated areas[4].
- Enhanced Operational Flexibility: Integrating machine learning and optimization algorithms in hybrid microgrids allows for better forecasting and management of energy resources, leading to improved operational flexibility and reduced dependency on external power sources [2].
- Peer-to-Peer Energy Trading: Hybrid microgrids can engage in peer-to-peer energy trading, which enhances energy security by allowing microgrids to share resources and balance supply and demand more effectively. This trading model promotes microgrid cooperation and reduces the impact of localized disruptions [5].

C. Challenges and Considerations

- Complexity and Cost: Hybrid microgrids offer significant benefits but introduce system design and operation complexity. The initial costs of setting up these systems can be high, although they may be offset by long-term savings and increased resilience [6].
- Uncertainty in Renewable Energy Supply: Reliance on renewable energy sources introduces variability and uncertainty in the power supply, which must be managed through robust optimization and control strategies to ensure consistent energy security [7].

In contrast to traditional grid systems, which are often centralized and vulnerable to large-scale disruptions, hybrid microgrids provide a decentralized approach that enhances resilience and energy security. However, the transition to hybrid microgrids requires careful planning and investment to address the integration challenges and ensure the reliability of renewable energy sources. As extreme weather events become more frequent, the role of hybrid microgrids in maintaining energy security is likely to grow, making them a critical component of future energy systems.

Definition Of Resilience Of Hybrid Microgrid From The Existing Studies

In the context of hybrid microgrids facing extreme weather, resilience is defined as the system's ability to maintain or quickly restore critical functions despite disruptions. This involves a combination of technological, operational, and strategic measures to ensure continuity and adaptability. However, existing studies reveal gaps in the comprehensive understanding and application of resilience, particularly in addressing uncertainties and integrating diverse energy resources. Below, we explore how resilience is defined and identify gaps in these definitions.

A. Definitions of Resilience in Hybrid Microgrids

- System Continuity and Critical Load Supply: Resilience is often defined as the ability of a power distribution system to continue supplying critical loads during multiple contingencies.
- This involves real-time monitoring, resilience assessment, and decision support tools to manage disruptions effectively [9]. Similarly, resilience in multiple energy carrier microgrids (MECMs) is defined by the ability to maintain supply continuity of critical loads during sudden islanding from upstream networks [11].
- Operational and Hardening Measures: Resilience is also characterized by integrating operational measures with infrastructure hardening decisions. This involves using stochastic robust optimization models to manage uncertainties and coordinate system operations with hardening strategies [10]. Distributed energy resources (DERs) and microgrid formations enhance resilience by providing flexible load restoration strategies [14].
- Technological Integration and Automation: Advanced technologies, such as machine learning and automation, are emphasized in enhancing grid resilience. These technologies improve situational awareness and decision-making capabilities, allowing for better management of extreme weather events and other disruptions [12].

B. Identified Gaps in Resilience Definitions

- Uncertainty Management: While some studies address uncertainties through probabilistic models and robust optimization, more comprehensive frameworks are needed to handle the wide range of uncertainties associated with extreme weather events and other disruptions [10] [11].
- Integration of Diverse Energy Resources: The complexity of integrating various energy resources, such as electric, gas, and heat networks, is not fully addressed. More holistic approaches are needed considering the interdependencies between different energy carriers and their impact on resilience [11] [13].
- Participatory and Normative Approaches: The normative aspects of resilience, such as stakeholder participation and the consideration of human well-being, are often implicit and not critically examined. This highlights a gap in the participatory approaches needed to develop more inclusive and comprehensive resilience strategies [15].
- Broader Sustainability Challenges: While resilience to climate change is a dominant theme, research efforts must broaden to address other sustainability challenges that impact resilience, such as social and economic factors [15].

In contrast to many studies' technical and operational focus, a broader perspective on resilience considers the system's capacity to adapt, recover, and grow in response to challenges. This includes technological and infrastructural measures and social, economic, and environmental dimensions. Addressing these broader aspects can lead to more robust and sustainable resilience strategies for hybrid microgrids facing extreme weather.

Assessment Of Resilience Of Hybrid Microgrid Against Extreme Weather Events

Various methodologies have been used to assess resilience in hybrid microgrids against extreme weather events, each with strengths and limitations. These methodologies primarily focus on simulation-based assessments, optimization algorithms, machine learning techniques, and decision support systems. However, they often fail to address the full spectrum of uncertainties and interdependencies inherent in microgrid systems. Below, we explore these methodologies and their limitations in detail.

A. Simulation-Based Resilience Assessment

- Microgrid Formation and Load Restoration: A simulation-based resilience assessment algorithm has been proposed to evaluate active distribution systems (ADSs) by considering microgrid formation based on grid-edge distributed energy resources (DERs). This method uses mixed integer linear programming (MILP) to optimize load restoration strategies and defines resilience indices to quantify resilience gains. However, the complexity of supply-demand relationships in ADSs can make resilience challenging to assess accurately, especially under uncertain conditions [16].

B. Optimization Algorithms

- Meta-Heuristic Optimization: The Prairie Dog Optimization (PDO) algorithm enhances control and power quality in hybrid microgrids by tuning controller parameters. This method has shown improvements in transient response and power quality, but it primarily addresses operational efficiency rather than resilience to extreme weather events [17].
- Proactive Scheduling and Islanding: A proactive scheduling approach using MILP has been developed for multiple energy carrier microgrids (MECMs) to ensure supply continuity during hurricanes. This method considers the interdependence of electric, gas, and heat networks, but its effectiveness is limited by the complexity of modeling such interdependencies and the uncertainties in weather predictions [19].

C. Machine Learning Techniques

- Resilience Quantification: Machine learning-based techniques (MLBTs) have been applied to assess the resilience of multi-energy systems (MESs).
- These techniques help in planning and reliability assessment but often require extensive data and may not fully capture the dynamic nature of extreme weather events [18].

D. Decision Support Systems

- Real-Time Monitoring and Decision Support: The DINGO system provides real-time resilience management for power distribution systems, offering outage detection and restoration tools. While it enhances situational awareness, its reliance on real-time data can be a limitation in scenarios where data availability is compromised [20].

E. Restoration and Resilience Management

- Restoration Planning: A three-stage restoration strategy for interdependent power-gas systems has been proposed, focusing on sectionalizing systems into autonomous microgrids. This approach improves resilience but may not be feasible in all scenarios due to the need for extensive infrastructure modifications [21].
- Stochastic Robust Optimization: A multi-stage, robust optimization model coordinates hardening and operational measures for smart power distribution systems. This model addresses uncertainties in damage and repair processes but may be computationally intensive and require significant resources for implementation [22].

F. General Perspective

While these methodologies provide valuable insights into enhancing microgrid resilience, they often fail to address the complexities of extreme weather events fully. Integrating various energy systems, the need for real-time data, and the computational demands of advanced models are significant challenges. Future research could focus on developing more holistic approaches that combine these methodologies, incorporate real-time data analytics, and address the interdependencies of energy systems to improve resilience comprehensively.

Interdisciplinary Approaches To Enhance Understanding Of Resilience Of Hybrid Microgrid

Interdisciplinary approaches can significantly enhance the understanding of resilience in hybrid microgrids under extreme weather conditions by integrating insights from various fields, such as engineering, environmental science, and social systems. These approaches allow for a comprehensive analysis of the complex interactions between microgrid components and external stressors, leading to more robust and adaptive systems. The following sections explore how different disciplines contribute to this understanding.

D. Engineering and Technological Innovations

- Microgrid Management Systems: Integrating building management systems with microgrid operations can optimize energy distribution during outages. Microgrids can maintain essential services even during extreme weather events by prioritizing critical loads and utilizing distributed energy resources (DERs). This approach is validated through real-time simulations, demonstrating its effectiveness in enhancing resilience [24].
- Hybrid Power Plant Design: Optimizing the physical layout and design of hybrid power plants, which combine wind, solar, and storage, can improve resilience against production disruptions. Ensuring these plants can continue supplying power during extreme weather contributes to grid stability and reliability [25].
- Smart Inverter Integration: Advanced inverters can provide essential grid services, such as voltage and frequency regulation, crucial for maintaining microgrid stability during extreme conditions. Power hardware-in-the-loop (PHIL) testing allows for evaluating these technologies in real-time scenarios, enhancing their integration into microgrids [30].

E. Environmental and Climate Considerations

- Heat Wave and Blackout Interactions: The concurrence of heat waves and electrical grid failures can drastically increase mortality and morbidity rates. Understanding these interactions highlights the need for resilient grid designs that can withstand such compound events, emphasizing the importance of environmental considerations in microgrid resilience planning [23].
- Stochastic Robust Optimization: By incorporating probabilistic models of extreme weather events, such as hurricanes, into grid planning, systems can be better prepared for uncertainties. This approach allows for the coordination of hardening and operational measures, enhancing the resilience of power distribution systems [26].

F. Social and Systemic Perspectives

- Resilience as a Boundary Object: The concept of resilience can serve as a boundary object, facilitating communication across disciplines. This approach integrates social and political determinants into resilience planning, ensuring that microgrid systems are technically robust and socially equitable [31].
- Skeleton-Network Strategy: A skeleton-network strategy can prioritize component recovery, reducing downtime and service disruption by modeling the interdependencies between electricity and gas systems. This method demonstrates the importance of considering systemic interdependencies in resilience planning [29].

G. Risk Management and Optimization

- Risk-Averse Optimization: Utilizing scenario-based stochastic optimization and risk measures like Conditional Value at Risk (CVaR) can improve the resilience of complex engineering systems. This approach addresses uncertainties in the recovery process, ensuring that microgrids can quickly adapt to and recover from extreme events [27].
- Interval Mathematics for Data Uncertainty: Interval mathematics can provide reliable system performance estimates under various fault conditions to manage data uncertainties in resilience analysis. This method enhances the accuracy and reliability of resilience assessments [28].

While interdisciplinary approaches offer comprehensive solutions, integrating diverse methodologies and perspectives remains challenging. The complexity of hybrid microgrids and the dynamic nature of extreme weather events require continuous collaboration and innovation across disciplines. By leveraging the strengths of each field, we can develop more resilient and adaptive microgrid systems capable of withstanding future challenges.

Existing Research Gaps In Resilience Of Hybrid Grids And Their Redressal

Given the increasing frequency and intensity of extreme weather events, the resilience of hybrid microgrids against them is a critical area of research. Despite advancements, several research gaps remain in understanding and enhancing their resilience. Addressing these gaps involves improving grid infrastructure, optimizing hybrid power plant designs, and developing robust management strategies to handle uncertainties and disruptions.

A. Infrastructure Resilience and Optimization

- Grid Hardening and Operational Measures: Integrated approaches that combine grid hardening with operational measures to enhance resilience are needed. The multi-stage stochastic robust optimization model proposed for intelligent power distribution systems highlights the importance of effectively coordinating these measures to manage uncertainties. This model can be adapted for hybrid microgrids to optimize hardening decisions and operational strategies, thereby improving resilience against extreme weather events [32].
- Physical Design of Hybrid Power Plants: Optimizing the design and layout of hybrid power plants, such as wind-solar-battery systems, is crucial for resilience. The methodology for optimizing these plants at the component level can help ensure they withstand production disruptions and continue to supply power during extreme weather events. This approach can be further refined to address specific challenges hybrid microgrids face [33].

B. Uncertainty Management and Robust Planning

- Stochastic Programming and Risk Management: Stochastic programming models, such as the nonlinear two-stage stochastic programming (NTSSP) model, can enhance resilience by optimizing resource allocation under weather-related risks. These models can be adapted to hybrid microgrids to improve pre-event mitigation and post-event recovery planning, addressing the uncertainties associated with extreme weather events [34].
- Interval Mathematics for Data Uncertainty: Another research gap concerns addressing data uncertainties in resilience analysis. The interval mathematics-based methodology provides a framework for reliable resilience analysis by representing transition probabilities as intervals. This

approach can be applied to hybrid microgrids to improve resilience planning and operation under uncertain conditions [37].

C. Demand Response and Renewable Integration

- Survivability-Oriented Demand Response: Implementing demand response programs triggered by local resources rather than market price signals can enhance microgrids' resilience. These programs can minimize load shedding and renewable curtailment during emergencies, thus maintaining stability and reducing operational costs [38].

D. Broader Perspectives and Challenges

While the above strategies focus on technical and operational improvements, broader challenges such as policy gaps and socio-economic impacts also need attention. For instance, the interaction between heatwaves and poor air quality, which exacerbates health risks, highlights the need for integrated policy responses considering environmental and public health aspects [36]. Additionally, conceptualizing resilience in broader contexts, such as human health and community resilience, can provide valuable insights for developing comprehensive resilience frameworks for hybrid microgrids [35].

Specific Aspects Of Resilience In Hybrid Microgrid During Extreme Events

Resilience in hybrid microgrids during extreme weather events is a critical area of research, especially as climate change increases the frequency and severity of such events. While significant progress has been made in understanding and enhancing the resilience of these systems, certain aspects remain underexplored. This response synthesizes insights from the provided research papers to identify these gaps and suggest areas for further investigation.

A. Underexplored Aspects of Resilience in Hybrid Microgrids

Health Impacts and Social Dimensions

- The intersection of grid failures and extreme weather events, such as heatwaves, has profound health implications. Research indicates that concurrent blackouts during heat waves can significantly increase mortality and morbidity rates, yet the social and health dimensions of resilience in microgrids are not thoroughly addressed [39]. This highlights a need for more studies focusing on the human impact of microgrid failures during extreme weather events.

Integration of Building Management Systems

- The potential for buildings to contribute to microgrid resilience through integrated management systems is underexplored. While some research has examined the role of building management in prioritizing energy distribution during outages, the full potential of this synergy remains untapped mainly [40]. Further research could explore how building management systems can be optimized to enhance microgrid resilience.

Data Uncertainty and Advanced Analytical Techniques

- The use of advanced data-driven techniques, such as machine learning, to manage uncertainties in grid operations during extreme events is still developing. While some studies have begun exploring these possibilities, more comprehensive frameworks incorporating data uncertainties into resilience planning [42] [44] are needed. This includes developing robust models that can predict and mitigate the impacts of extreme weather on microgrid operations.

Economic and Environmental Assessments

- The economic and environmental implications of different microgrid configurations under extreme weather conditions are not fully understood. Although some research has compared the resilience of various power system configurations, more detailed analyses are needed to assess these systems' cost-effectiveness and environmental impact [45]. This could guide the development of more sustainable and resilient microgrid solutions.

Comprehensive Risk Management Frameworks

- Existing research often focuses on either pre-event mitigation or post-event recovery, but there is a lack of integrated frameworks that address both stages comprehensively. Developing such frameworks could enhance the overall resilience of microgrids by ensuring that both preventive and reactive measures are optimized [42] [46]. This includes the need for models that can handle large-scale data and complex network interactions.

B. Broader Perspectives

While microgrid resilience's technical and operational aspects are crucial, the ethical and social dimensions must also be considered. Resilience strategies that do not account for social contexts may inadvertently exacerbate inequalities or overlook community-specific needs [43]. Additionally, the integration of advanced technologies must be balanced with considerations of accessibility and equity to ensure that all communities benefit from enhanced resilience measures. This broader perspective is essential for developing holistic and inclusive resilience strategies for hybrid microgrids.

Effective Strategies For Enhancing Resilience Of Hybrid Microgrid And Key Challenges In Implementation

Enhancing the resilience of hybrid microgrids against extreme weather events is crucial for maintaining energy supply and minimizing disruptions. Effective strategies involve a combination of technological, infrastructural, and management approaches, while key challenges include integration complexity, cost, and cybersecurity concerns. The following sections detail these strategies and challenges, drawing insights from the provided research papers.

A. Effective Strategies for Enhancing Resilience

- Integration of Renewable Energy Sources (RESs): Integrating RESs, such as solar and wind, into microgrids enhances resilience by diversifying energy sources and reducing dependency on a single supply chain. Artificial intelligence (AI) can optimize the integration process, improving operational accuracy and prediction control, which is crucial during extreme weather events [47].
- Stochastic and Robust Optimization Models: Stochastic programming and robust optimization models can significantly enhance microgrid resilience. These models help plan and manage uncertainties associated with extreme weather, allowing for better resource allocation and system-hardening decisions [48] [53].
- Skeleton-Network-Based Strategies: This approach identifies critical components within integrated electricity-gas systems to prioritize protection and recovery efforts. It ensures that essential services are maintained or quickly restored, reducing the impact of outages [49].
- Hierarchical Control Methods: Implementing accurate peer-to-peer hierarchical control methods in hybrid DC microgrid clusters can improve system stability and adaptability. This method allows for efficient coordination among sub-microgrids, enhancing the system's overall resilience [54].

B. Key Challenges in Implementation

- Complexity and Integration Issues: Integrating diverse energy sources and advanced control systems into existing infrastructure is complex. It requires careful planning and coordination to ensure compatibility and optimal performance [47] [54].
- Cost and Resource Allocation: Implementing resilience-enhancing strategies often involves significant upfront costs. Balancing economic efficiency with robust infrastructure is a major challenge, as highlighted by the need for cost-effective resource allocation models [48] [52].
- Cybersecurity Threats: Microgrids' increased reliance on digital communication and control systems makes them vulnerable to cybersecurity threats. Ensuring secure data exchange and protecting critical infrastructure from cyber-attacks is essential for maintaining resilience [51].
- Data and Risk Management: Effective resilience strategies require comprehensive data collection and risk assessment. Developing frameworks that integrate risk management with resilience enhancement can be challenging but is necessary for systematic improvement [55].

C. Broader Perspectives

While the focus is often on technological and infrastructural solutions, resilience also involves psychological and social dimensions. The concept of resilience extends beyond physical systems to include the ability of communities to adapt and recover from disruptions. This broader perspective emphasizes the importance of community engagement and social support systems in enhancing overall resilience [50]. Additionally, integrating resilience strategies across domains, such as telecommunications and gas networks, highlights the interconnected nature of modern infrastructure and the need for holistic approaches to resilience management [55].

Potential Solutions/Strategies To Fill The Research Gaps In Resilience Of Hybrid Microgrid During Extreme Weather Conditions

Several strategies and solutions have been proposed across various studies to address the research gaps in resilience for hybrid microgrids during extreme weather events. These strategies focus on enhancing microgrids' robustness, adaptability, and recovery capabilities, crucial for maintaining a power supply during and after extreme weather conditions. The proposed solutions range from advanced optimization models and infrastructure hardening to innovative design and operational strategies.

D. Multi-Stage Optimization and Hardening

- A multi-stage stochastic robust optimization (SRO) model has been developed to manage resilience in smart power distribution systems. This model integrates operational measures with hardening decisions, effectively addressing uncertainties in planning due to extreme weather events. The SRO model uses probabilistic information to optimize hardening decisions, significantly influencing resilience operational measures [56].
- A nonlinear two-stage stochastic programming (NTSSP) model is proposed to enhance infrastructure resilience under weather-related risks. This model optimizes pre-event mitigation and

post-event recovery, focusing on resource allocation to improve system robustness and redundancy. The NTSSP model effectively balances economic and efficiency considerations in risk mitigation [57].

E. Integration of Renewable Energy and Storage

- Optimizing the design and layout of hybrid power plants, which combine wind, solar, and storage, is crucial for resilience. These plants are designed to withstand production disruptions and supply power during extreme weather events. The methodology involves optimizing the plant at the component level to ensure continuous power production despite disruptions [58].

F. Building and Microgrid Synergy

- Enhancing resilience through the synergy between microgrids and building management systems is another strategy. This involves a bi-level optimal sequence of operations for managing controllable devices in microgrids, prioritizing critical loads during outages. This approach ensures that available energy is directed to essential services, improving post-disaster service restoration [59].

G. Skeleton-Network Strategy

- A skeleton-network-based strategy is proposed for integrated electricity-gas systems (IEGSs), focusing on quick recovery of infrastructure functionality. This strategy identifies critical network components and prioritizes their protection and recovery, significantly reducing the time consumers are affected during outages [60].

H. Resilience Assessment and Mitigation

- A procedure for evaluating and enhancing the resilience of distribution networks against flooding threats has been developed. This involves assessing the resilience of each network asset and implementing countermeasures to reduce the impact of flooding events. The method has been applied to a real distribution network, demonstrating its effectiveness in improving resilience [62].

I. Data-Driven Resilience Analysis

- An interval mathematics-based methodology is introduced for reliable resilience analysis of power systems, accounting for data uncertainties. This approach uses time-varying interval Markov Chains to assess system resilience, providing a scalable and computationally efficient framework for resilience analysis [63].

While these strategies offer promising solutions, it is essential to consider the broader context of resilience research. The National Institutes of Health (NIH) emphasizes a comprehensive understanding of resilience across various domains, including environmental and community resilience. This perspective highlights the need for interdisciplinary approaches and collaboration to address the complex challenges posed by extreme weather events [61].

CONCLUSION

This research paper provides an in-depth exploration of hybrid microgrids' vital role in meeting the expected increase in energy needs that society will face shortly. It carefully examines the key factors contributing to the challenges involved in deploying and functioning hybrid microgrids. The study places significant focus on specific issues and highlights existing research gaps concerning the resilience and robustness of hybrid microgrids under extreme environmental conditions. Through this detailed analysis, the paper aims to shed light on promising avenues for future developments and innovations in hybrid microgrids, especially regarding their performance during severe and unpredictable weather events.

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