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Editorial

Resilience of power grids in the face of climate change: an urgent challenge for engineering

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Abstract: This editorial reflects on the systemic vulnerability of power grids to extreme weather events during 2025, specifically citing European heatwaves and blackouts in Chile. It advocates for a holistic engineering approach to resilience, defined as the capacity to anticipate, adapt, and restore operations under climate stress. Looking ahead, it highlights the role of artificial intelligence and advanced modeling in managing the complexities of renewable energy integration. Reaffirming the journal's commitment, it calls for research that aligns technological innovation with societal well-being and inclusion.

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1. Introduction

In recent years, power systems around the world have been exposed to increasingly demanding operating conditions, challenging long-standing paradigms of grid design, planning, and operation. The intense heatwaves experienced across several regions of Europe—leading to record electricity demand, reduced generation efficiency, and transmission constraints—together with the large-scale blackout in Chile, which left millions of users without electricity, provide compelling evidence of the growing vulnerability of power grids to complex, high-impact disturbances [1–4]. These events should not be interpreted as isolated failures, but rather as early manifestations of systemic stress in energy infrastructures operating under changing climatic conditions.

Traditionally, power system planning and operation have been grounded in principles of reliability, economic efficiency, and operational security, under the implicit assumption of relatively stationary climate patterns and predictable demand profiles. However, the increasing frequency and severity of extreme weather events—such as heatwaves, prolonged droughts, floods, wildfires, and severe storms—directly challenge these assumptions. In this evolving context, resilience has emerged as a central concept in power system engineering, understood not merely as the ability to prevent failures, but as the capacity of a system to anticipate disruptions, withstand adverse conditions, adapt dynamically, and restore operation within acceptable time-frames.

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From an engineering perspective, addressing power grid resilience requires moving beyond the deployment of isolated technological solutions. While distributed generation, microgrids, energy storage systems, and advanced monitoring, protection, and control technologies are essential components, resilience is fundamentally an emergent property. It arises from the complex interactions among physical infrastructure, control and communication systems, human operators, regulatory frameworks, and the environmental context in which the system operates. Consequently, resilience-oriented planning demands a holistic and interdisciplinary approach that integrates technical, organizational, and environmental dimensions.

The growing penetration of variable renewable energy sources, particularly solar photovoltaic and wind generation, introduces additional layers of complexity into resilience assessment. Although these technologies are indispensable for decarbonization and energy diversification, their large-scale integration modifies system dynamics by increasing variability, reducing synchronous inertia, and intensifying reliance on power electronic interfaces. As highlighted in recent comprehensive reviews, climate change further compounds these challenges by altering resource availability and increasing operational uncertainty, reinforcing the need for climate-aware grid design and operation [5].

Insights from the literature indicate that climate change is already affecting the efficiency, reliability, and predictability of renewable energy technologies. Rising ambient temperatures influence photovoltaic performance, extreme weather events threaten physical infrastructure and shifting climatic patterns impact wind and hydropower resources. When combined with high renewable penetration levels, these effects can undermine system stability if not properly addressed through advanced forecasting, flexible resources, and adaptive control strategies. Resilience must therefore be treated as a core design criterion, rather than an auxiliary or post-hoc consideration in energy system planning [5].

Complementary analyses of highly decarbonized and zero-emission power systems further demonstrate that low-carbon pathways do not automatically guarantee robust and reliable operation. Studies focusing on the interaction between climate variability and technological uncertainty reveal that systems optimized primarily for emissions reduction may exhibit structural vulnerabilities when exposed to extreme events or unfavorable climate conditions [6]. These findings underline the importance of aligning long-term climate goals with short-term operational resilience, adequacy, and flexibility requirements.

In parallel, research centered on sustainable hydropower development highlights that changes in hydrological regimes—such as altered precipitation patterns, glacier retreat, and increased drought frequency—pose significant challenges to the operational resilience of hydropower-dominated systems [7]. Given the critical role of hydropower in many regions, particularly in Latin America, these challenges demand adaptive operational strategies, diversified energy mixes, and integrated water–energy planning approaches that explicitly account for climate uncertainty.

For regions particularly vulnerable to climate change, such as Latin America and the Caribbean, strengthening power system resilience extends beyond purely technical considerations. Prolonged power outages directly affect essential services, including healthcare, water supply, telecommunications, and public safety, thereby amplifying social and economic impacts. In this sense, resilience-oriented engineering must also account for issues of equity, accessibility, and societal well-being, ensuring that the benefits of the energy transition are both reliable and inclusive.

Within this evolving landscape, applied mathematics, advanced modeling techniques, and computational tools play a strategic role in enhancing power system resilience. Climate-informed risk assessment, extreme-event simulation, probabilistic reliability analysis, and optimization under uncertainty are increasingly necessary to capture the non-linear and non-stationary nature of future operating conditions. At the same time, the growing use of artificial intelligence and data-driven methods offers promising opportunities for predictive maintenance, situational awareness, and adaptive control, while also raising critical questions regarding model robustness, transparency, and interpretability under stressed conditions.

Addressing these challenges requires the promotion of an interdisciplinary research agenda that integrates power systems engineering, electronics, control, computer science, applied mathematics, and climate science. Equally important is the evolution of engineering education, which must incorporate competencies related to resilience, sustainability, and uncertainty management, preparing professionals capable of designing and operating energy systems in increasingly complex and dynamic environments.

Within this framework, *Transactions on Energy Systems and Engineering Applications (TESEA)* reaffirms its commitment to serving as an academic platform for the dissemination of rigorous and applied research addressing current and future challenges in energy systems. The recent events in Europe and Chile underscore both the urgency of the problem and the relevance of resilience-oriented research. This is an invitation for the academic and professional community to contribute to the development of more resilient, adaptive, and sustainable power grids, capable of effectively responding to the challenges imposed by climate change in the twenty-first century.

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