Chapter 1
Recent Advances in Power Grid Technology

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ABSTRACT

This chapter, per the authors, this chapter explores the evolution of modern energy system technology thru the integration of Artificial Intelligence, Machine Learning, and Blockchain technologies. This examines how this new technology is changing the way energy is created, delivered, and managed, making infrastructure safer, more efficient, and more sustainable. Most of the discussion will center on the latest advancements in smart grids, decentralized energy trading, and microgrid systems. Additionally, it discusses the use of AI in predictive analytics and blockchain to make data more open. We carefully review issues such as scalability, data protection, and regulatory compliance. We are also reviewing ways to promote ethical governance and responsible innovation. Ultimately, this chapter emphasizes the potential of revolutionary intelligent and transparent systems to enhance global energy resilience while safeguarding human dignity, trust, and sustainability in the digital age.

1. INTRODUCTION: THE EVOLUTION OF THE POWER GRID

Since it was first created, the electricity grid, which is one of the most vital aspects of modern society, has changed a lot. More than 1,000 scholarly publica-

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tions from 2015 to 2022 examined the incorporation of blockchain technology into smart grids, however there are still large research gaps in empirical validation and architectural frameworks, according to (Lampropoulos, 2024). The rising occurrence of tropical cyclones attributed to global warming presents a significant risk to the reliable functioning of coastal power grids, highlighting the necessity for the development of methods to quantitatively evaluate the risks associated with spatiotemporal grid anomalies (Geng & Chen, 2025). Most electrical networks in the early 1900s were centralized systems that transferred power from a few large facilities to a lot of smaller ones. These early grids weren't very intricate. They only let electricity flow in one way, from where it was made to where it was used. These systems worked well for the limited demand and predictable usage patterns of the time, but they weren't equipped for the dynamic and always-changing energy situation of the 21st century. With the growing integration of distributed energy resources into contemporary power grids, operational risks have transitioned from conventional overloads resulting from individual equipment failures to multifaceted abnormalities induced by intricate, large-scale distributed energy disruptions (Geng & Chen, 2025). The world is moving toward smarter and more flexible power networks because more people are using renewable energy sources and want their power to be reliable and long-lasting. Old grids were meant to be robust, not adaptable. They used a lot of fossil fuel power plants that could be modified to meet demand with a lot of accuracy. The system was based on the premise that consumption would be predictable and that there would only be a few locations where generation could be controlled. Random fluctuations in distributed flexible resources like electric vehicles, photovoltaics, and wind power can, via the amplification effect of large-scale disturbances, push the grid's operation beyond safe stability limits (Geng & Chen, 2025). But as wind and solar power became more popular, it became evident that traditional grid management has its constraints because these resources are not always accessible and might vary. Generation might change in ways that aren't intended, which could make things unstable. This would mean that new means to predict, keep an eye on, and control things would be needed. The modern grid needs digitalization and automation to grow. Operators can keep an eye on voltage, frequency, and load across enormous networks thanks to improved sensors, meters, and communication networks that give them real-time information about system conditions. This extensive information makes predictive analytics possible. With predictive analytics, you can undertake maintenance before problems emerge and send generation assets out in the best way possible. AI-powered control systems can modify generation, storage, and load immediately instantly in ways that older grids couldn't. The electricity grid of today is becoming more intelligent and dynamic, allowing it to improve itself.

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