

PERFORMANCE METRICS AND UNIFIED APPROACHES FOR DIGITAL TWIN IMPLEMENTATION IN ENERGY SECTORS

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ABSTRACT

Digital Twin (DT) technology has the potential to transform the energy sector by creating a virtual representation of physical assets, processes, and systems. This capability enables real-time updates through data integration from IoT sensors, machine learning algorithms, and advanced analytics. By enhancing the monitoring, simulation, and optimization of energy infrastructure—ranging from conventional power plants to renewable energy sources—DTs contribute to a more efficient and resilient energy ecosystem. As the energy sector undergoes digital transformation, the adoption of DTs is becoming essential for improving operational efficiency, system reliability, and sustainability.

Despite the significant advantages, the implementation of DT technology faces numerous challenges that must be addressed. This paper investigates the gap between conceptual frameworks and practical applications of DTs in the energy sector, exploring the added value that effective implementation can provide. We offer an overview of real-world applications of DTs in energy, highlighting successful case studies and identifying critical components and performance metrics necessary for various applications.

For example, while in power generation, DTs facilitate predictive maintenance and performance optimization, enabling operators to foresee equipment failures and minimize downtime, in renewable energy systems, such as wind turbines and solar farms, DTs enhance resource forecasting by integrating environmental data, thereby improving reliability and managing operational risks effectively. Furthermore, in grid management, DTs are pivotal in the transition to smart grids. By simulating the real-time state of the grid, these virtual models enable utility operators to predict and manage load fluctuations, integrate decentralized energy resources, and detect anomalies proactively.

This paper aims to provide a comprehensive understanding of the current landscape of DT technology in the energy sector, along with its challenges, opportunities, and future directions for research.

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