Available Online: 28 May 2026 DOI: 10.54254/3029-0880/2026.33901

Research on the application of metaverse technology in digital power grids

***Juan Wang*[1,2*], *Li Wang*[3]**

[1]School of Economics and Management, Xi'an University of Posts and Telecommunications, Xi'an, China
[2]Blockchain and Digital Finance Committee, Beijing Computer Federation, Beijing, China
[3]School of Electronic Engineering, Xi'an University of Posts and Telecommunications, Xi'an, China

*Corresponding Author. Email: jane@xupt.cn

Abstract. With the advancement of the "dual-carbon" strategy and the rapid construction of new power systems, traditional power grids are facing challenges such as large-scale renewable energy integration, increasingly complex operating structures, and insufficient intelligent operation and maintenance capabilities. Metaverse technology integrates digital twins, the Internet of Things, artificial intelligence, 5G communication, big data, and virtual reality technologies, providing a new development direction for digital power grid construction. Based on the Fujian digital power grid pilot project, this paper systematically studies the application of metaverse technology in digital power grids. The study analyzes the development background of new power systems and the limitations of traditional grids, proposes the overall architecture of metaverse-based digital power grids, discusses key technologies such as digital twins, AI, and blockchain, and further explores practical scenarios including intelligent inspection, renewable energy forecasting, carbon emission monitoring, and disaster warning. The results show that metaverse technology can effectively improve the visualization, intelligence, and collaborative operation capabilities of power grids, providing important support for future smart energy systems.

Keywords: metaverse, digital power grid, digital twin, smart grid, renewable energy forecasting, carbon emission monitoring

1. Introduction

In recent years, the global energy structure has been rapidly shifting from traditional fossil energy to renewable energy. Following China's "carbon peak" and "carbon neutrality" goals, renewable energy installations have increased significantly. Wind and photovoltaic power generation account for an increasing proportion of the power system, promoting the transformation of traditional power grids into new power systems. However, renewable energy generation is characterized by volatility, randomness, and intermittency, which brings significant challenges to grid stability and operation. At the same time, the increasing number of transmission and distribution devices has significantly increased the complexity of power grid operation and maintenance. Traditional management methods relying on manual inspection and decentralized information systems can no longer satisfy the requirements of highly reliable, flexible, and intelligent future power systems. Under this background, digitalization and intelligence have become the core development directions of power grids. Metaverse technology provides a new technical path for digital power grid construction through the integration of digital twins, real-time interaction, virtual-real integration, and intelligent analysis technologies [1].

2. Overview of metaverse technology and digital power grids

Metaverse technology is a new digital space integrating virtual reality, augmented reality, digital twins, artificial intelligence, blockchain, cloud computing, and IoT technologies. Unlike traditional Internet systems that mainly focus on information sharing, the metaverse emphasizes immersive real-time interaction among humans, devices, and environments. In the power industry, metaverse technology enables the digital mapping of substations, transmission lines, towers, wind farms, photovoltaic stations, and energy storage systems. Through digital twin technology, physical equipment can be synchronized with virtual models in real time, enabling operators to intuitively monitor grid operating conditions and improve fault detection efficiency [2]. The metaverse also supports immersive experiences through VR and AR technologies. Operators can enter virtual substations, inspect equipment, analyze operating parameters, and conduct virtual training in highly realistic environments. In addition, AI algorithms support intelligent decision-making by analyzing historical and real-time operational data to achieve fault prediction, renewable energy forecasting, and maintenance optimization.

3. Architecture of metaverse-based digital power grid

The metaverse-based digital power grid platform mainly consists of the physical layer, component layer, service layer, application layer, and user layer. The physical layer includes transmission lines, substations, distribution rooms, renewable energy stations, and energy storage equipment. The component layer includes smart cameras, drones, environmental sensors, power sensors, and intelligent gateways for data acquisition and transmission. The service layer is the core of the digital power grid. It provides model management, data fusion, spatiotemporal analysis, scene orchestration, operation engines, and 3D cloud rendering services. Through spatiotemporal analysis, the system can dynamically simulate complex operating scenarios and analyze potential risks in real time. Scene orchestration functions are used to construct intelligent inspection scenarios, disaster warning scenarios, virtual training scenarios, and dispatching command scenarios. The operation engine is responsible for state synchronization, real-time computing, AI reasoning, and business scheduling. Meanwhile, GPU-based cloud rendering technology enables real-time visualization of large-scale digital scenes. The application layer includes renewable energy forecasting, intelligent inspection, carbon monitoring, fault diagnosis, and risk warning. The user layer serves grid operators, renewable energy enterprises, government departments, and dispatching centers [3, 4].

4. Digital twin technology

Digital twin technology is the core technology of metaverse digital power grids. Its purpose is to establish virtual models synchronized with physical equipment and operating environments. The architecture mainly includes data acquisition, 3D modeling, state synchronization, real-time simulation, and intelligent prediction. The system collects operational data through IoT sensors, SCADA systems, GIS systems, drones, and video monitoring equipment. BIM technology, GIS modeling, and CAD tools are then used to construct highly accurate virtual models of substations, transmission lines, renewable energy facilities, and environmental terrain. Real-time synchronization continuously updates virtual models according to physical operating conditions. In addition, simulation technologies can analyze typhoon impacts, equipment fault propagation, renewable energy fluctuations, and power flow changes. AI algorithms are further applied to transformer lifetime prediction, renewable energy forecasting, and equipment health assessment.

5. Key technologies

IoT technology is the foundation for comprehensive perception in digital power grids. Sensors deployed on transmission lines, substations, transformers, wind turbines, and photovoltaic modules continuously collect temperature, humidity, vibration, current, and environmental information. AI technology is mainly applied to fault identification, renewable energy forecasting, and intelligent maintenance decision-making. Through image recognition and pattern analysis, AI can identify equipment abnormalities such as insulator damage, conductor foreign objects, and overheating. 5G communication technology provides high bandwidth, low latency, massive connectivity, and high reliability for drone video transmission, cloud rendering, remote inspection, and intelligent dispatching. Blockchain technology is mainly applied to carbon emission monitoring. It supports encrypted data storage, tamper-proof carbon records, and intelligent contract verification, thereby improving the reliability and transparency of carbon supervision.

6. Application scenarios

The intelligent inspection scenario uses drones and robots to automatically inspect transmission lines and substations, significantly improving inspection efficiency and reducing labor costs. Renewable energy forecasting scenarios establish virtual models of wind farms and photovoltaic stations, integrate meteorological data and historical power generation data, and improve forecasting accuracy through AI algorithms [5]. Fault diagnosis systems can quickly identify abnormal conditions such as temperature rise, current fluctuations, and partial discharge, and automatically generate maintenance recommendations. Disaster warning systems establish aerodynamic field models, terrain models, and temperature field models to predict typhoons, heavy rainfall, icing, and other natural disasters.Carbon emission monitoring systems support enterprise-level carbon analysis, regional carbon visualization, and government carbon verification.

7. Challenges and future development

Although metaverse technology provides new opportunities for digital power grid construction, several challenges still exist, including data security risks, high deployment costs, lack of unified technical standards, and large-scale computing requirements. Digital twin modeling, 5G deployment, and GPU cloud rendering all require significant investment. At the same time, real-time rendering, AI training, and massive data analysis place higher requirements on cloud computing and edge computing capabilities. In the future, digital twin technology is expected to cover the entire process of power generation, transmission, distribution, and consumption. AI-based autonomous dispatching, virtual power plant collaboration, and intelligent carbon trading will further promote the development of smart energy systems.

8. Conclusion

Metaverse technology is accelerating the transformation of traditional power grids into intelligent, visualized, and virtual-real integrated systems. By integrating digital twins, AI, IoT, 5G, and blockchain technologies, digital power grids can achieve comprehensive perception, intelligent decision-making, and real-time interaction. The Fujian pilot project has demonstrated the practical value of metaverse technology in intelligent inspection, renewable energy forecasting, and carbon emission monitoring. With the continuous development of AI, communication, and computing technologies, metaverse-based digital power grids will play an increasingly important role in future smart power systems.

References

[1] Wang, F. (2022). Research on digital twin and smart grid development. *Automation of Electric Power Systems, 46*(12), 1–10.

[2] Li, Q. (2023). Application prospects of metaverse technology in smart energy. *Electric Power, 56*(4), 15–23.

[3] Chen, T. (2022). Research on new power systems and digital energy technology. *Power System Technology, 46*(9), 3250–3258.

[4] Liu, W. (2021). Research on the application of artificial intelligence in smart grids. *Power Informatization, 19*(6), 44–50.

[5] Zhang, L. (2022). Development status and trends of digital twin technology. *Acta Automatica Sinica, 48*(8), 1881–1895.