# Design of an energy management system based on digital twins

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## ABSTRACT

In the construction of clean and low-carbon community energy management systems, the challenges of the new era of low-carbon community development lie in monitoring and utilizing the massive panoramic information obtained from physical equipment within the community, constructing digital twin models of intelligent clean energy systems, and achieving multi-energy complementarity and energy conservation and emission reduction. Based on the optimization and complementarity of multi-energy interconnected systems and the coordinated operation control technology of "source-grid-load-storage," this paper designs a digital twin-based green and low-carbon community energy system operation management platform that integrates the needs of multiple business scenarios. By integrating modeling, simulation, artificial intelligence, and hierarchical control across multiple temporal and spatial scales through digital twin technology, this platform offers functions such as energy planning, operation and control, demand response, distributed energy trading, and carbon neutrality services. It addresses the issues of information barriers hindering the development of clean energy systems such as "source-grid-load-storage integration" in energy systems, effectively supporting key aspects of integrated energy systems, including planning and design, optimized operation, online safety analysis, and equipment health management.

**Keywords:** Digital twin, multi-energy, optimized complementarity, operational control, platform

## 1. INTRODUCTION

### 1.1 Research background

Climate change is a global issue facing humanity. With the increase of carbon dioxide emissions and greenhouse gases in various countries, global warming, rising sea levels, increasing extreme weather, and frequent natural disasters have been triggered, posing a serious threat to the common living environment of humanity. In this context, addressing climate change and reducing carbon emissions has become a global consensus. At the 2020 United Nations General Assembly, China solemnly committed to peaking carbon dioxide emissions before 2030 and striving to achieve carbon neutrality before 2060[1]. Fossil energy consumption is one of the main sources of carbon dioxide emissions. Therefore, adjusting the energy structure, increasing the proportion of clean energy, and building a green and low-carbon society are the necessary paths to achieve carbon neutrality goals[2]. As the main source of fossil energy consumption, cities consume 75% of the world's energy, and their carbon emissions account for approximately 75% to 80% of the total global carbon emissions. As an important component of cities, creating low-carbon communities plays a positive role in creating a healthy, coordinated, and sustainable human living environment[3].

### 1.2 Purpose and significance

For the construction of low-carbon communities, whether it is to realize the modeling of clean energy system or the coordinated operation control of "source network load and storage", it is difficult to understand and control the operating state and characteristics of the system at a deep level. At this time, the integration of multi-source measurements, the analysis of system characteristics, the prediction of development trends, and the optimization of control decisions need to be completed more efficiently in the digital space. The digital twin technology is the key technology to support this new energy system. Digital twin technology makes full use of refined physical model, intelligent sensor data, operation and maintenance history and other data, integrates electrical, magnetic, thermal, fluid and other multi-disciplinary, multi-

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physical quantity, multi-scale, multi-probability simulation process, complete the mapping of low-carbon community system in virtual space, can be updated in real time and dynamic evolution, and establish accurate connections between the physical world and the digital world. It can help solve the technical problems in the optimization of multi-energy interconnection system, and support the accurate simulation and control of energy interconnection network from multiple angles. At the same time, the digital twin technology combines modeling, simulation, artificial intelligence, and hierarchical control at multiple time and space scales to provide functions such as energy planning, operation and control, demand response, distributed energy trading, and carbon neutral services, effectively supporting the planning and design, optimized operation, online security analysis, equipment health management and other major links of the integrated energy system[4].

### 1.3 Research level at home and abroad

In recent years, digital twin technology has been applied in various fields such as energy internet planning, grid analysis, and battery management. References[5-10] have respectively established digital twin platforms for energy internet planning, digital twin models for inverters, digital twin models for photovoltaic power generation devices, and digital twin models for battery management systems. They have also explored the concept of digital twins in smart energy systems and proposed an online grid analysis system based on digital twin technology. However, the application of digital twins in the operation and optimization of integrated energy systems remains limited.

In the construction of clean energy digital twin system, how to monitor and use the massive panorama information obtained from the physical equipment in the community, how to build a smart clean energy system model based on the digital twin, and how to achieve multi-energy complementarity and energy saving and emission reduction are the great challenges of low-carbon community construction in the new era. The definition and application architecture of digital twin technology in clean energy system still need in-depth research, and the application experiment of digital twin technology in energy system is also in the preliminary verification and exploration stage.

## 2. KEY TECHNOLOGY RESEARCH

In the context of dual-carbon, platform construction faces multi-subject needs, involving various industries, in addition to energy, but also increased production, operation, construction, transportation, green plant and other aspects of carbon data. Based on multi-temporal simulation, multi-energy interconnection system optimization and complementarity, “source network load and storage” coordinated operation control technology achievements and theoretical tools, combined with the actual scene of the demonstration area, the use of digital twin technology can complete a variety of analysis and research in the virtual environment that is difficult to carry out in the real world.

### 2.1 Optimization and complement of multi-energy interconnection systems

Based on the current state of the park integrated energy system, the use of digital twin technology to build a diversified planning state digital park integrated energy system. Firstly, the system operation optimization modeling and simulation are carried out on the planned energy system to solve the optimal cost, carbon emission, new energy consumption and other index data after the optimized operation of each planned state. Then, more planned digital integrated energy systems are iteratively constructed and solved. Finally, a comparative evaluation of the economic, environmental, and safety operational benefits of various planning states under the multi-energy complementarity strategy is conducted to obtain the optimal operational strategy and planning scheme

### 2.2 Coordinated operation control of “source network load storage”

Digital twin technology is used to realize multi-time scale simulation of the park’s integrated energy system, complete the planning and design, system online security analysis, equipment health management and other functions aiming at coordinated operation of “source network load and storage”. Firstly, in the planned energy system, the optimization solution aiming at “maximum local absorption of PV and optimal regional power flow” is given. Secondly, the real-time simulation of electromagnetic transient supports the refined transient evaluation and analysis of distribution network level under multi-control strategy. Finally, the typical power router converter equipment is focused to complete the equipment and health management including condition monitoring and fault diagnosis.

### 2.3 Platform architecture design

Under the dual-carbon background, the platform construction faces the needs of multiple entities, involving various industries. Beyond energy, it also encompasses carbon data from production, operations, construction, transportation, greening, and other aspects. Based on the achievements and theoretical tools of the multi-energy interconnected system optimization and complementarity, as well as the coordinated operation control technology of "source-grid-load-storage," combined with the actual scenarios in demonstration areas, digital twin technology can be utilized to complete various analytical studies in the virtual environment that are difficult to carry out in the real world.

The green low-carbon community energy system operation management platform based on digital twin is shown in Figure 1, which can be divided into three main bodies: physical layer, resource layer and functional layer. Its functional layer includes energy planning, operation and control, demand response, distributed energy trading, carbon neutral services, etc. The platform resource layer includes digital twin modeling service sub-platform, digital twin real-time simulation sub-platform, artificial intelligence sub-platform, etc., to build a layered control architecture with multiple spatio-temporal scales.

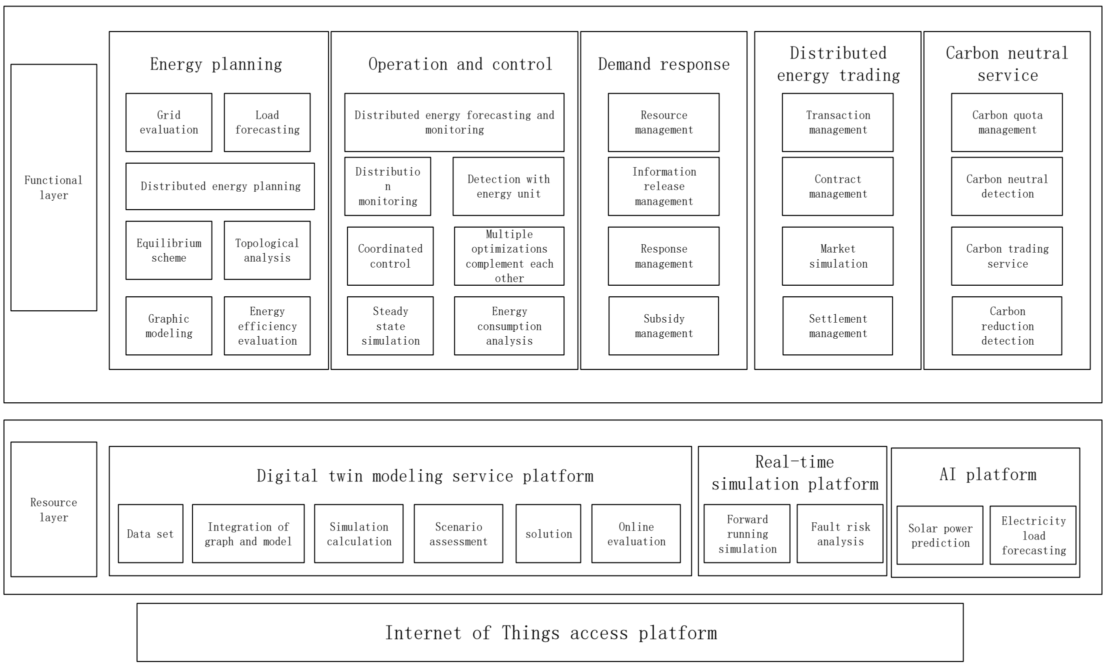


Figure 1. Platform architecture.

As is shown in Figure 2, the resource layer is subdivided into the data layer and the mechanism layer, and the functional layer includes the presentation layer and the interaction layer, that is, the five major parts of the digital twin universal architecture: physical layer, data layer, mechanism layer, presentation layer and interaction layer.

The physical layer mainly contains the physical entities of equipment and facilities involved in the operation process of the energy system; the data layer relies on the Internet of Things edge IoT agents, sensing devices, sensor networks, IoT platforms, etc., to provide the data sources required for the realization of digital twins, and undertakes the functions of upstream sensing data collection and downstream control command execution between the twin and the physical object; the mechanism layer includes the modeling, model deduction, and evolution functions of the equipment digital twin. The modeling of digital twins proceeds from three levels: equipment level, unit level, and system level, and performs multi-dimensional, multi-space-time, and multi-scale mechanism models and data-driven models on demand; the presentation layer is the upper layer of the application in digital twins, which uses advanced technologies such as visualization, virtual reality, and augmented reality to display the operating status, results, and other information of digital twins to users in an intuitive and easy-to-understand manner. The interaction layer is the bridge connecting users and digital models in the digital twin system. It provides intuitive and easy-to-use interaction interfaces and tools, enabling users to conveniently view, operate, and analyze digital twin models.

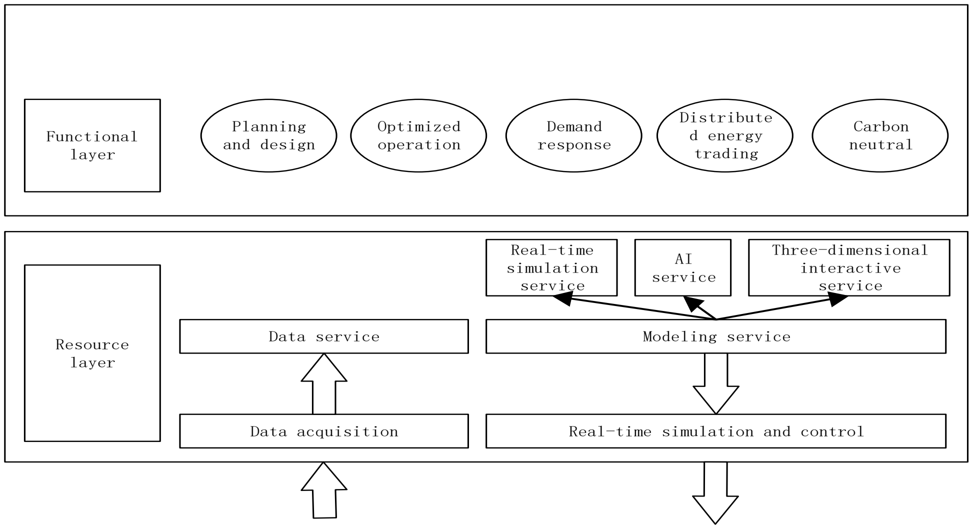


Figure 2. Layered architecture.

## 2.4 Functional design

(1) Energy planning and operation management

The energy planning and operational management section includes optimized design and medium- and long-term forecasting.

In the optimization design, two working modes are designed, among which the automatic mode is the platform based on the existing energy system, the optimal design scheme (reconstruction/expansion, line and pipeline layout adjustment) is proposed to achieve the optimization goal, while meeting all aspects of constraints. The manual mode is also set, which can make optimization plan manually and give immediate feedback on optimization effect. Under different modes, the input of current energy supply and demand data (energy structure, network cable layout, historical consumption), optimization objectives (formulated in combination with future forecast information), optimization constraints (energy balance, spatial physical constraints, economic constraints, carbon emission constraints, etc.) can be realized, and the 3D energy system effect diagram under the optimization scheme will be displayed immediately. When the constraints are not met, the 3D energy system effect diagram will be highlighted. It also shows the trend of indicators such as economy/carbon emission that change with an optimization adjustment.

(2) Operation and control

The operation and control functions cover the accurate prediction function of new energy generation power and electricity load based on machine learning, the function of multi-energy complementarity, and the function of source network load and storage coordination. The accurate prediction function of new energy generation power and electricity load is based on machine learning technology and historical wind speed/power data series to model and achieve accurate prediction of regionally distributed new energy generation power. Through the accurate prediction of wind and solar power generation power, the elasticity of distribution network can be optimized, resources can be rationally allocated, and the operation level of power grid can be improved. The multi-energy complementary function supports the multi-time scale optimization model of various energy forms such as electricity, heat and gas, and the optimization algorithm includes multi-objective optimization of carbon emission indicators or carbon emission constraints. In the coordination function of “source network load and storage”, “source” includes a variety of clean energy such as wind power and photovoltaic; “Network” includes AC-DC hybrid distribution network; “Load” includes electric vehicle charging stations, residential power loads, industrial large users, etc.; “Storage” includes power grid side energy storage, user side energy storage, etc.

(3) Carbon neutral services

Help parks and enterprises to clearly understand their own carbon emissions and which business processes produce the most carbon emissions, and conduct comprehensive monitoring of park carbon emissions, building carbon emissions monitoring, key equipment or business carbon emissions monitoring. Carbon accounts for buildings, individuals, equipment and businesses can be set up, and it can clarify the attribution of carbon footprints. From people, equipment, process flow, buildings, parks and other levels of carbon emission characteristics analysis and trend prediction, to achieve building carbon portrait, personal carbon portrait.

According to a long-term observation of energy supply and consumption in power supply stations, we can analyze the trends of carbon peaking and carbon neutrality, analyze related factors and key links, and assist in formulating targeted energy-saving and carbon reduction programs; Referring to domestic and foreign carbon emission calculation standards, one-click report can be generated, which is more convenient for parks and enterprises to report emission reduction data and greatly reduce manpower input.

(4) Demand response

According to the interpretation of the corresponding mechanism and incentive policy of the demand, combined with the operation of the demand resources of the park, the project can be developed to respond to the demand response, and the declaration, clearance and settlement management can be carried out. When the response is executed, the first is to analyze the data and report the aggregate response capability. Second, the upper-level demand response system issues execution instructions again according to the platform's reporting capability and needs, and the instructions include the required response capacity. After receiving the instruction, the platform will store the instruction in the database, optimize the scheduling module to periodically read the relevant parameters of the database, schedule the controllable resources according to the reported response ability, and issue the execution plan curve. The results were analyzed after the response.

(5) Distributed energy trading

Distributed energy trading includes trading, contracts, settlement management, and simulation of energy trading markets. At present, the main model is "selling electricity through the wall". Additionally, it manages energy providers, energy consumers, account opening information, etc. Between energy suppliers and energy consumers, the buyer and seller relationship are established through the contract mechanism, and the contract relationship is bound. These contracts cover both parties, time limits, electricity supply, electricity consumption, settlement methods, exit mechanisms, default mechanisms, etc. According to the contract offer, the fees are settled between energy providers, energy consumers, service platforms, operators and other parties (including whether network fees are required, etc.).

## 3. CONCLUSION

Based on the optimization and complementarity of multi-energy interconnected systems and the coordinated operation control technology of "source-grid-load-storage," combined with the actual scenarios in demonstration areas, a digital twin-based green and low-carbon community energy system operation management platform architecture has been designed utilizing digital twin technology and integrating the needs of multiple business scenarios. This platform architecture has undergone functional design, addressing the issue of information barriers that hinder the development of clean energy systems such as "source-grid-load-storage integration" in energy systems. It has achieved the integration of status and operational data from heterogeneous clean energy equipment driving green and low-carbon communities, as well as the mapping and interaction of massive multi-source real-time data. In the future, relying on this digital twin-based green and low-carbon community energy system operation management platform, further application demonstrations will be conducted to provide theoretical and technical support for the friendly access and flexible interaction of high-proportion distributed power sources and new sources such as electric vehicles, as well as the deep integration and mutual support between future complex clean energy systems and active distribution systems.

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