Research on a digital twin dynamic polymerization technology

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ABSTRACT

In this paper, a kind of digital twin dynamic polymerization technology based on clustering and intelligent analysis is studied. In the first step, the goal and business requirements of device-level digital twin polymerization are studied, and the principle of hierarchical and distributed dynamic polymerization of device-level digital twin is proposed. The second step analyzes the dynamic characteristics of the county energy Internet source network charge and storage, and studies the spatio-temporal dynamic aggregation modeling technology of the device-level digital twin based on the dynamic characteristics of the source network charge and storage. The third step is to study the hierarchical polymerization framework and polymerization method of the virtual power plant at the source, load and storage side facing the distributed multi-level interaction framework of the county energy Internet, the hierarchical polymerization framework and polymerization method of the county energy Internet side, and the hierarchical polymerization framework and polymerization method of the virtual power plant at the source, load and storage side facing the county network side.

Keywords: Digital Twin, Fake and real data, Data Interconnect Mapping

1. INTRODUCTION

1.1 Research background

In recent years, facing the problem of energy transition, the country has continuously promoted the development of renewable energy. In December 2020, the Central Economic Work Conference set the goal of "China's carbon dioxide emissions strive to peak by 2030 and achieve carbon neutrality by 2060". The 14th Five-Year Plan set the target of reducing carbon dioxide emissions per unit of GDP by 18%, implementing the target of Nationally Determined Contributions to address climate change by 2030, and anchor-setting efforts to achieve carbon neutrality by 2060. Relevant national policies indicate that "carbon peak, carbon neutrality" has become the core issue of China's modernization, and the key to solve this problem lies in the effective development and utilization of photovoltaic, wind power and other new energy[1].

new technologies such as big data and digital twins have been gradually applied in China's industrial field, but their application in the collaborative interaction between source network, load storage, and other aspects is still immature[2]. The interaction mechanism and operation mode of high proportion distributed photovoltaic and other multi type, multi agent, source, load, and storage resources in the county energy internet are complex, and advanced technical means such as data mining, artificial intelligence, and digital twins are integrated to promote the integration and application of energy technology and information technology, breaking through strong fluctuations, multi-dimensional monitoring, real-time perception of information status, construction of multiple source device twins, and digital twin biological management Multiple technical bottlenecks such as collaborative interaction and deduction of multi-level digital twins of the energy internet, and the development of a county level energy internet source network load storage collaborative interactive digital twin system to support the digital construction of the energy internet, thereby guiding the safe and efficient operation of the county level energy internet physical system, improving the safe operation level of the power grid and the new energy consumption capacity[3-4].

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Seventh International Conference on Mechatronics and Intelligent Robotics (ICMIR 2023), edited by Srikanta Patnaik, Tao Shen, Proc. of SPIE Vol. 12779, 127790E · © 2023 SPIE · 0277-786X · Published under a Creative Commons Attribution CC-BY 3.0 License · doi: 10.1117/12.2688686

1.2 Purpose and significance

Cluster analysis refers to the process of grouping collections of physical or abstract objects into classes of similar objects. The goal of cluster analysis is to collect data on a similar basis and classify it into different classes or clusters. Therefore, objects in the same cluster have great similarities, while objects in different clusters have great differences. The quality of clustering results is judged by the set property, including the separation between classes and the coupling within classes. Cluster analysis is one of the main tasks of data mining, which can be used as an independent tool to obtain the distribution of data, observe the characteristics of each cluster data, and focus on the specific cluster cooperation for further analysis. Traditional clustering algorithms can be divided into five categories: partition method, hierarchical method, density-based method, grid-based method and model-based method. When dealing with actual complex data, especially for high-dimensional data and large data, traditional clustering methods often fail. In this case, high-dimensional clustering analysis emerges at the historic moment and becomes an important research direction of cluster analysis[5].

Due to the wide variety, large scale, and diverse operational characteristics of county level energy internet source and load resources, cluster analysis is one of the methods used in the project for distributed source and load storage resource aggregation. Through distributed source and load storage resource aggregation, a virtual power plant is formed to participate in the interactive operation of the energy internet[6].

Based on the spatiotemporal characteristics of distributed source and load resources within the county energy internet, and facing the requirements of distributed multi-level collaborative interaction of the county energy internet, a full process management mechanism and modeling technology suitable for the digital twin of the county energy internet are proposed, laying the foundation for achieving efficient collaborative interaction and operational deduction of the county energy internet based on the digital twin, Through the twin discovery authentication modeling mechanism, model consistency and scalability are achieved, improving the digital management capabilities of the energy internet, and helping to achieve distributed source load storage resources to participate in the interactive operation of the county level energy internet under the protection of privacy information.

1.3 Research level at home and abroad

In China, in terms of digital twin layered dynamic polymerization. Document [7] describes the definition, composition, and characteristics of digital twins, and proposes the connotation of digital power grid based on digital twins for the first time. The concept, characteristics, and derivative relationship between digital power grid and smart grid are analyzed in detail. A digital power grid architecture including physical power grid, perception layer, transmission layer, data layer, platform layer, and application layer is constructed, and the key technologies of digital power grid are summarized. Based on the concept, basic architecture, and characteristics of digital twinning, the document [8] proposes the connotation of digital twinning power grids, constructs a framework for digital twinning power grids, explains the operation mode of digital twinning power grids, analyzes the key technologies of digital twinning power grids, and proposes typical applications of digital twinning technology in power grid enterprises from four levels: equipment layer, power grid layer, business layer, and operation management layer. The above documents have constructed digital twin power grid systems from different application levels under the same power grid, and have not conducted in-depth research on hierarchical dynamic aggregation of digital twins at different levels at the virtual power plant level.

In foreign countries, in terms of digital twin layered dynamic polymerization. Literature [9] proposes a six layer digital twin architecture and describes its prototype software implementation. The issues and principles of consumer infrastructure ontology modeling are described, including customer loads, low-voltage distribution network components, small power generation devices, and electrical energy storage devices. The digital twin model composed of the proposed method is used to calculate the optimal configuration of renewable energy hybrid power supply systems. Document [10] proposes a dynamic scheduling management method for digital twin simulation computing tasks in multiple energy systems. Based on the stable computing completion time of simulation computing tasks, a comprehensive priority index was designed to quantify the execution order of simulation computing tasks. On the basis of this comprehensive priority index, a task allocation mechanism aimed at minimizing the computing completion time of applications was proposed. The above literature proposes a hierarchical construction method for digital twins and a dynamic scheduling management method for digital twins, but does not consider the dynamic and hierarchical aggregation between digital twins.

2. KEY TECHNOLOGY RESEARCH

The overall technical route is shown in Figure 1, and the research is carried out in three steps in sequence.The objective and business requirements of device-level digital twin aggregation are studied, and the principle of hierarchical and distributed dynamic aggregation of device-level digital twin is proposed. The dynamic characteristics of the county energy Internet were analyzed, and the spatio-temporal dynamic aggregation modeling technology of device-level digital twins based on the dynamic characteristics of the source network charge and storage was studied, as well as the complementary regulation and aggregation modeling technology oriented to the collaborative interaction of the county energy Internet. The hierarchical aggregation technology of virtual power plants at the source, load and storage side for the distributed multi-level interactive framework of county energy Internet, the hierarchical aggregation technology at the county energy Internet side, and the hierarchical aggregation technology from the virtual power plants at the source, load and storage side to the county network side are studied.

2.1 Dynamic polymerization principle of source charge storage digital twins

First, combined with the goal of power grid safe operation and new energy consumption under the background of county energy Internet, the interactive business needs of different subjects under the power trading and operation regulation mode are studied. Then, based on the comprehensive analysis of the subject, topological relationship, spatio-temporal characteristics and other factors of various digital twins of source, load and storage. The principles of digital twin polymerization based on hierarchical polymerization, distributed polymerization, spatio-temporal dynamic polymerization and complementary regulatory polymerization are proposed.

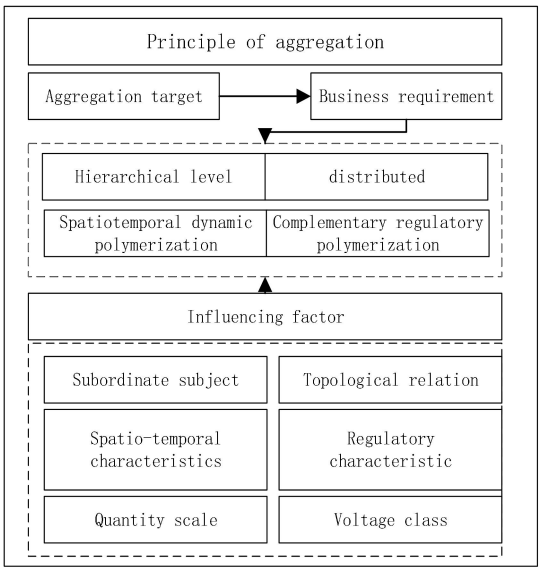

Fig. 1. Dynamic polymerization principle of source charge storage digital twins .

In power trading, the interactive business needs of different subjects are as follows: power generation enterprises, power users, and power trading markets. In the power operation regulation mode, the interactive business demands among different subjects are as follows: power dispatching center, power generation enterprise and power user, and power market regulator.

The principle of dynamic aggregation of digital twins means that the modeling results should be updated and optimized over time to better reflect the actual situation and realize the dynamic interaction between digital twins and physical systems. This principle helps the digital twin always keep up-to-date data and accurate models, making it more realistic and more accurate to predict future performance. At the same time, it can also help the digital twin to carry out real-time data exchange and interaction between the actual equipment, so as to realize more adaptive, efficient and safe automated operation. The principles of digital twin polymerization based on different polymerization modes are as follows:

(1) Hierarchical aggregation principle: digital twins should be hierarchical aggregation according to their functions and levels to ensure efficient operation of the whole system. Specifically, digital twins should include multiple levels, from

physical devices, equipment clusters, and terminals, to subsystems, parent systems, system levels, and ultimately, the goal of emulating the entire power system.

(2) Distributed aggregation principle: digital twins should be aggregated through a distributed system to ensure load balancing and information synchronization among nodes. Specifically, the digital twin should adopt the distributed data storage and calculation method, and connect each subsystem to realize the real-time transmission and sharing of information.

(3) Principle of spatio-temporal dynamic aggregation: the digital twin should be able to track and respond to the dynamic changes of the power system in time and space in real time, as well as continuously update and optimize in real time, so as to achieve more accurate prediction and optimization. In particular, digital twins should be able to integrate multiple data sources, including historical data, real-time data, external data, and so on, to achieve more comprehensive and accurate modeling.

(4) Principle of complementary regulation and aggregation: digital twins should consider the complementarity and synergy of systematic regulation, so as to form a more complete and effective regulation mode. Specifically, the digital twin should consider the coordination between different regulation methods, including regulation based on market mechanism, traditional dispatch regulation, new energy regulation, load side response, etc., to ensure the stable and efficient operation of the entire power system.

2.2 Dynamic aggregation technology of virtual power plant digital twins based on spatiotemporal dynamic characteristics of source network load storage

Firstly, the ownership subject, topological relationship, spatio-temporal characteristics and regulatory characteristics of device-level digital twins in the energy Internet are analyzed. Secondly, topological changes of device-level digital twins in different levels of county energy Internet are analyzed by dynamic topological analysis method. Then, dynamic coupling characteristics of device-level digital twins in different spatio-temporal scales are analyzed based on dynamic characteristics of source charge and storage. Finally, based on clustering, intelligent optimization and other analysis methods, the space-time dynamic polymerization technology of virtual power plant digital twin and complementary regulation polymerization technology are proposed.

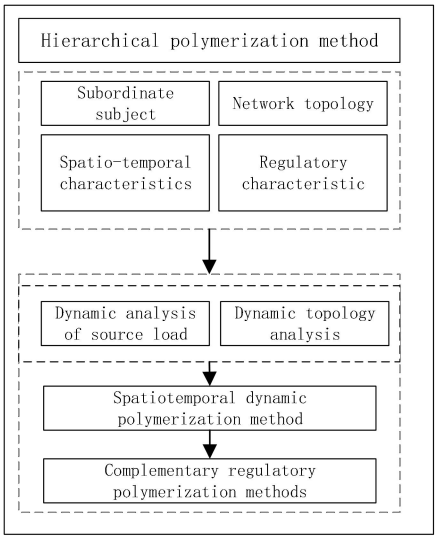

Fig. 2. Dynamic aggregation technology of virtual power plant digital twins based on spatiotemporal dynamic characteristics of source network load storage.

Device-level digital twin refers to a digital twin that is modeled and simulated based on a single device. In the energy Internet, device-level digital twins are typically created and used by:

Power generation enterprises: Power generation enterprises can use device-level digital twins for modeling and simulation of their power generation equipment to monitor equipment status in real time and optimize equipment operation strategies to improve power generation efficiency and reduce operating costs.

Power grid enterprises: Power grid enterprises can use equipment-level digital twins for modeling and simulation of their transmission equipment, so as to monitor equipment status in real time, manage and dispatch power operation, and ensure the safety and stability of the power grid.

Power users: Power users can use device-level digital twins to model and simulate their electrical equipment to monitor equipment status in real time and optimize energy consumption control strategies to reduce energy costs and improve efficiency.

The topological relationships of device-level digital twins are usually single point connections or point-to-point connections. In terms of spatio-temporal characteristics, device-level digital twins generally represent the real-time status and historical operation data of a single device, which can be analyzed in time domain, space domain or spatio-temporal combination. In terms of regulation characteristics, device-level digital twins can realize regulation and optimization of power equipment through real-time control of real-time data, such as improving power generation efficiency and reducing energy consumption of power equipment.

The dynamic topological analysis method is used to monitor and analyze the topological relationship between the device-level digital twins in the energy Internet in real time. The topological changes of the device hierarchy topology, the device group hierarchy topology, the station hierarchy topology, and the subsystem hierarchy topology are found. After understanding the topological changes between different levels of energy equipment, the dynamic coupling characteristics of the digital twins at the level of source, load and storage equipment in different spatio-temporal scales are analyzed. The dynamic coupling characteristics of source-load-storage device-level digital twins exist in different spatio-temporal scales, and the coupling characteristics are affected by the topological structure and running state of the energy equipment. In the time scale, the digital twin can represent the historical data and real-time state of energy equipment, while in the space scale, the digital twin can reflect the distance and correlation between different energy equipment. Therefore, the dynamic topological analysis method can be used to analyze the spatio-temporal dynamic characteristics of the source, load and storage device-level digital twins in different levels of county energy networks, so as to realize the dynamic coupling characteristics analysis of the source, load and storage device-level digital twins.

2.3 Hierarchical polymerization framework and process of multilevel virtual power plant digital twin

Firstly, according to the multi-level polymerization relationship between various distributed resources and virtual power plants at the source, load and storage side, a suitable hierarchical polymerization framework and polymerization method were proposed. Secondly, according to the layered management and control structures of different spatial scales, such as county energy Internet station, feeder, power transformation and supply area and county whole network, the layered polymerization framework and polymerization method of county energy Internet side are proposed. Finally, according to the technical requirements of various kinds of digital twins of source, load and storage and virtual power plants participating in the collaborative interaction of energy Internet at each level of county, the hierarchical polymerization framework and polymerization method of virtual power plants at the source, load and storage side to the county network are proposed.

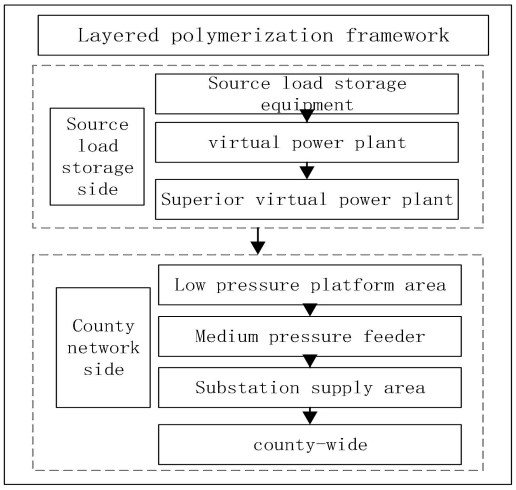

Fig. 3. Hierarchical polymerization framework and process of multilevel virtual power plant digital twin.

Based on the multi-level aggregation relationship between various distributed resources and virtual power plants at the source, load and storage side, an adaptive hierarchical aggregation framework and corresponding aggregation method can be established to balance the efficiency and accuracy of the system. The possible hierarchical polymerization framework and polymerization methods include low level polymerization, seed node level polymerization, upper level polymerization, etc., which can realize the multi-level polymerization of resources and the overall regulation of virtual power plant, and obtain more economic and social benefits.

According to the layered management and control structures of different spatial scales, such as county energy Internet station area, feeder line, power transformation and supply area and county whole network, the following layered polymerization framework and corresponding polymerization methods can be proposed:

(1) Platform level aggregation: At the platform level, through real-time monitoring and analysis of distributed energy resources, such as distributed power generation equipment, energy storage equipment, electric vehicles, etc., digital twins are established to realize the aggregation and management of energy flow, power flow and information flow within the platform. The aggregation method can adopt the algorithm based on graph theory to integrate the energy, load, power quality and other data of various distributed resources in the station, so as to realize the control of the station level.

(2) Feeder-level aggregation: At the feeder level, the feeder-level energy model is formed through the aggregation of the digital twins in the station area, so as to manage and control the feeder voltage, line loss and other conditions uniformly. The aggregation method can use the algorithm based on physical diagram to model the physical topology of the digital twins in each station area according to the principle of the calculation of electric energy flow and loss.

(3) Substation power supply area level aggregation: At the substation power supply area level, the digital twins of the feeder level can be aggregated to form a multi-level management and control hierarchy system for substation power supply area, so as to uniformly manage the power supply area feeder controlled by the substation and each station area belonging to the power supply area feeder. The aggregation method can adopt the algorithm based on the transmission equation to analyze and simulate the energy flow of the feeder, form the corresponding mathematical model, and complete the reliability evaluation and optimization control.

(4) county-wide network level aggregation: At the county-wide network level, digital twins of each power supply area can be aggregated to form an energy model of the county-wide network, so as to achieve integrated and efficient management. The aggregation method can adopt the method based on artificial intelligence and big data technology to carry out online processing and continuous optimization and update of energy data in each substation and power supply area, so as to continuously improve the efficiency and stability of the energy system.

According to the technical requirements of various kinds of source load storage and virtual power plant digital twins participating in the collaborative interaction of energy Internet at different levels of county, the following hierarchical polymerization framework and corresponding polymerization methods are proposed:

(1) Digital twin of energy industry: The whole life cycle of energy and the digital twin of all levels are carried out cross-level collaborative interaction. Through the integrated test platform built by digital twin, real-time monitoring of energy data, interaction, autonomous diagnosis, autonomous control and so on at all levels. Based on the digital twin, a data-driven multi-level prediction and analysis model can be established, and the collaborative protocol and hierarchical management and control strategy between different energy levels can be generated.

(2) Virtual power plant level aggregation: At the virtual power plant level, multiple distributed energy resources can be organically coordinated. For example, in a virtual power plant, multiple distributed resources such as power station, wind power, photovoltaic and energy storage are integrated into a virtual power plant. Resource integration optimization, interactive reserve, energy flow regulation, load balance and other functions are realized. The aggregation method can adopt the method based on big data technology to establish the digital twin of virtual power plant, and realize the reasonable scheduling of virtual power plant by predicting and adjusting various resource nodes in advance.

(3) Blockchain technology support: In the whole energy Internet, blockchain technology can support the security and sharing of energy data. Blockchain technology can establish new ways of sharing information between nodes by interacting closely with each other. To ensure data security and privacy, all levels of energy data are encrypted by key mapping and other information. The aggregation method can adopt electronic cryptography technology, digital signature technology and multi-point communication strategy to enhance data security and privacy.

3. CONCLUSION

By studying the hierarchical and distributed dynamic aggregation principle of device-level digital twins, the spatio-temporal dynamic aggregation modeling technology of device-level digital twins based on the dynamic characteristics of source network load and storage, and designing the interactive framework and process of distributed multi-level virtual power plant digital twins for county energy Internet, a digital twin aggregation method is proposed.

ACKNOWLEDGMENTS

This work is supported by Science and Technology Project of State Grid Corporation of China (Research on digital twinning management and interactive technology for efficient collaboration of county energy Internet, No. 5700-202224202A-1-1-ZN).

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