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Analysis of collaborative control technology and demonstration project of integrated energy system

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Abstract. Energy is the main driving force of economic development and social progress, and its production and supply relationship directly determines the destiny of the country. In recent years, there has been a boom in energy internet research at home and abroad. Aiming at the integrated energy system, this paper compares and analyzes the demonstration project of domestic and foreign integrated energy system, and points out the difference and gap between the domestic and foreign demonstration applications. Two kinds of technical routes for achieving coordination control of integrated energy system are proposed. The affecting factors of the development of integrated energy system are analyzed, and the key technologies for achieving collaborative control of integrated energy system are proposed.

1. Introduction

Energy Internet uses advanced power electronic technology, information technology and intelligent management technology, to build a large number of new power networks, petroleum networks, natural gas networks and other energy nodes consisting of distributed energy acquisition devices, distributed energy storage devices and various types of loads, in order to realize the energy exchange and sharing network of energy bi-directional flow. Integrated energy system is an important physical carrier of Energy Internet, and is the key to achieving technologies such as multi-energy complementary and cascade utilization of energy. It requires the participation of national institutions, energy suppliers and local users. According to geographical factors and energy generation /transmission /distribution /utilization characteristics, integrated energy systems can be divided into cross-regional, regional and user levels [1]. Regional integrated energy system is composed of intelligent power distribution system, medium-low pressure natural gas system, heat/cold/water system and other energy supply network with coupling interconnection, which plays the role of energy transmission, distribution, conversion and balance. The research object in this paper is mainly regional integrated energy system. Regional integrated energy system will be implemented as a functional area (such as an industrial park), which can achieve the production collaboration, pipe gallery collaboration, demand side collaboration and interaction between production and consumption of “electricity/hot/cold/gas” horizontal multi-energy system and the “source-network-load-storage” vertical multi-energy supply. It can promote the consumption of renewable energy, ensure the friendly access of the supply side and demand side elements, improve the comprehensive utilization efficiency of multiple energy sources,



finally, provide energy integration solutions for users in the region, which is the main form of energy for human society in the future.

2. Overview of integrated energy systems

Energy is the main driving force of economic development and social progress, and its production-supply relationship directly determines the destiny of the country. In the current energy consumption mode, there are fragmented and isolated problems between different kinds of energy or between different steps of the same kind of energy. The information barriers are serious so that the overall situation of urban energy operation and the interaction mechanism between energy sources is not clear and there is a lack of effective synergy between energy sources. In order to improve the overall efficiency of energy and the ability to absorb renewable energy, there is an increasingly urgent need for the interconnection and integration of multiple types of energy resources.

In recent years, there has been a boom in Energy Internet research and development at home and abroad. In 2008, both the United States and Germany started research or demonstration on Energy Internet [2]. In 2011, Jeremy Rifkin further promoted the concept of Energy Internet in the book of *The Third Industrial Revolution* [3]. Since 2012, there have been several Energy Internet seminars in China and relevant studies have been started. For example, “Renewable Energy Internet” frontier forum organized by China Electric Power Research Institute; “The Global Energy Internet” proposed by State Grid Corporation of China; “Energy Internet Research Institute” established by Tsinghua University in April 2015. In July 2015, the “Guiding Opinions of the State Council on Actively Promoting “Internet +” Actions” officially adopted “Internet +” smart energy as a key action; In February 2016, “The guidance on promoting the development of “Internet +” smart energy” put forward specific guidance on the development of Energy Internet. In March 2016, the Energy Internet entered “China's 13th five-year plan”. In October 2017, State Grid Corporation of China issued a document: taking advantage of the resources of all parties in the company, strengthening and expanding the integrated energy service business, promoting the company's transformation from electric energy suppliers to integrated energy service providers, creating new profit growth points and upgrading company's market Competitiveness.

3. Demonstration application of integrated energy system

3.1. Foreign demonstration projects

At present, the research on Energy Internet in foreign countries is not limited to the theoretical aspect, and there are already countries and regions to carry out practical research [4-5]. In the study of foreign integrated energy system demonstration projects, the National Science Foundation of the United States proposed to build a future renewable electric energy delivery and management (FREEDM) system [5]. After further research and development, it has now become an Energy Management System with characteristics of initial Internet Energy. FREEDM system has the following characteristics: 1) Universal energy information interactive interface, which can guarantee access of distributed energy storage, photovoltaic and other distributed power sources and realize “plug and play”. 2) The information flow of each energy module of the system automatic upload cloud processing and analysis system. The cloud processing and analysis system returns the calculation result to the operation and planning module of the control system to realize the cyclic correction of the planning scheme and the system operation scheme; 3) Energy Management System can conduct state detection on the accessed equipment, and collect energy supply and demand data to realize the refined control. The control of load is no longer a simple on-off control, whose power and voltage can be adjusted.

In 2010, the United States launched the Mad River pilot project [5], in which 6 commercial, industrial sites and 12 residential areas are selected, and 280kW propane gas turbine engine, 100kW biodiesel generator, 30kW micro-sized gas turbine engine, a large number of photovoltaics and fans are involved to test the modeling and simulation methods, protection and control strategies and economic benefits of micro-grid and to achieve the optimal coordinated control of energy.

The demonstration project of Yellowknife in Canada uses the ICES (Integrated Community Energy Solutions) technology combined with the integrated energy system concept to transform the town's energy system, achieving full utilization of waste heat and geothermal heat, reducing waste emissions and increasing recycling and reuse of waste.

Professor G. Anderson of the ETH University in Zurich proposed the "Energy Hub" model [4], which was derived from the concept of a hub in computer science, also known as the Energy Control Center. The "Energy Hub" carries out optimized collaborative control on the source side and controlled load side through super short-term load forecasting and real-time on-line monitoring of various types of distributed energy. The scale of the "Energy Hub" can cover a household or even an entire city. Later, the German Federal Ministry of Economics and Technology and the Ministry of the Environment jointly launched the E-Energy program, which aims to build a future energy system based on Information and Communications Technology (ICT), which is mainly reflected in: 1) Through intelligent Information and Communications Technology, the load optimization management control of the user can be deeply penetrated to the user's household appliances level, and users can choose the electricity time freely, whether it is a relatively low lighting load or a large-capacity load of personal swimming pool, refrigeration equipment, electric vehicle, etc. 2) The user's electricity information is collected intensively through advanced electronic measuring instrument to provide the required information for the network node of the intelligent E-Energy system. The system will automatically analyze the user's electricity habits and other data information. 3) The system collects and predicts the big data information of the energy supply in the affected area, such as illumination and wind speed, and sends the information together with the user's electricity information and power generation information to the ICT gateway of the energy user, and also sends the information to the energy supplier, carrier, system operator control system. The system also provide optimal power generation planning and utilization plan for both parties to achieve dual-sided coordination and optimization of power supply and demand.

The EU ELECTRA demonstration project [4] aims to realize the full utilization of large-scale renewable energy, focusing on the stable operation of the smart grid in Europe in 2030. As for power grid of different scales and voltage levels, the research on operation control, energy storage technology, power market mechanism, etc. is conducted.

The EU E-DeMa project [4] focuses on the construction of the high permeability distributed energy community, in which users, energy suppliers, energy vendors, equipment operators and other roles are integrated to make the virtual energy trading including electricity and spare capacity. The transmission, distribution, management and control of energy is realized through intelligent energy routers.

The University of Manchester has done some research on integrated energy system design, operation method and its demonstration project [5]. The project integrated user monitoring terminal and developed a integrated energy system including electricity, heat, gas and water system, and a user interaction platform, which have been successfully applied in Manchester. The interactive platform integrates the Manchester energy system from three aspects: energy utilization model, energy saving strategy and demand response.

Japan has realized regional energy management integration in Kashiwa-no- ha. Kashiwa-no- ha Smart City [5] has used the Regional Energy Management System, in which the energy information of the entire region has been centralized for unified treatment and the simple energy conservation has been developed into an energy circulation and energy reserves. The demonstration project has been conducted.

3.2. Domestic demonstration projects

There has been integrated energy system demonstration projects in domestic [4]. Yanqing County of Beijing has abundant renewable resources, and has the largest demonstration cluster in China. The renewable energy penetration rate is extremely high, which provides favorable conditions for the construction of the active distribution network demonstration project. Its energy system supports flexible and secure access to distributed generators, which improves the optimization and

configuration capability of energy transmission network and the absorption capacity of distributed energy.

Shanghai Disney Resort is the first resort park with distributed power technology in the world. Its demonstration area uses GE's distributed energy technology to provide a supply system of cold, heat, electricity and compressed air. The project uses a centralized control system for energy stations effectively integrated with the user-side Energy Management System to ensure that all systems in the station are always in an efficient state of operation. The energy utilization efficiency of the whole system is improved through valley collection and peak release of various energy storage technologies.

In Tianjin china-singapore eco-city demonstration project, efficient utilization of cold, heat and electricity is achieved in the form of micro-grid. its demonstration area is an energy supply site with comprehensive needs, and the energy system integrates multiple energy inputs, multiple product outputs and multiple energy conversion units.

In Tongli New Energy Town Project, relying on the advantages of the permanent meeting site of the International Energy Reform Forum, a regional Energy Internet will be built with clean energy as the direction, electricity as the center, the power grid as the platform and the energy alternative as emphasis. A clean, low-carbon, safe and efficient new energy system will be built to lead the urban energy development. The source-network-load-storage coordination control system will be constructed to realize the coordinate optimization control of the source, network, load and storage in the whole Tongli Comprehensive Energy Service Center, improve the overall safety level and operational efficiency of the service center regional power grid, and maximize the consumption of clean energy.

In Lian Island Integrated Energy Service Demonstration Project, a source-network-load-storage coordination control system integrating power electronic transformers, distributed energy, Combined Cooling Heating and Power (CCHP), wave energy, AC/DC power distribution network, energy storage device, etc. will be built to realize integration optimization among various types of power equipment in the coordination area.

3.3. Comparison of domestic and foreign demonstration projects

Foreign researchers mainly use rapid simulation technology to conduct coordinated control of power supply side and controlled load side collaborative control through the super short-term load forecasting and real-time online monitoring of all kinds of distributed energy. The integration model construction and coordination control of source-network-load-storage has not been reported. Domestic researchers focus on respective construction and implementation of distributed power supply access, micro-grid energy storage system, electric vehicle charging facility, distribution automation and other subsystems. The research and application of coordination control of source-network-load-storage through designing the hierarchical model, control architecture, optimization goal and coordination strategy is still in its infancy.

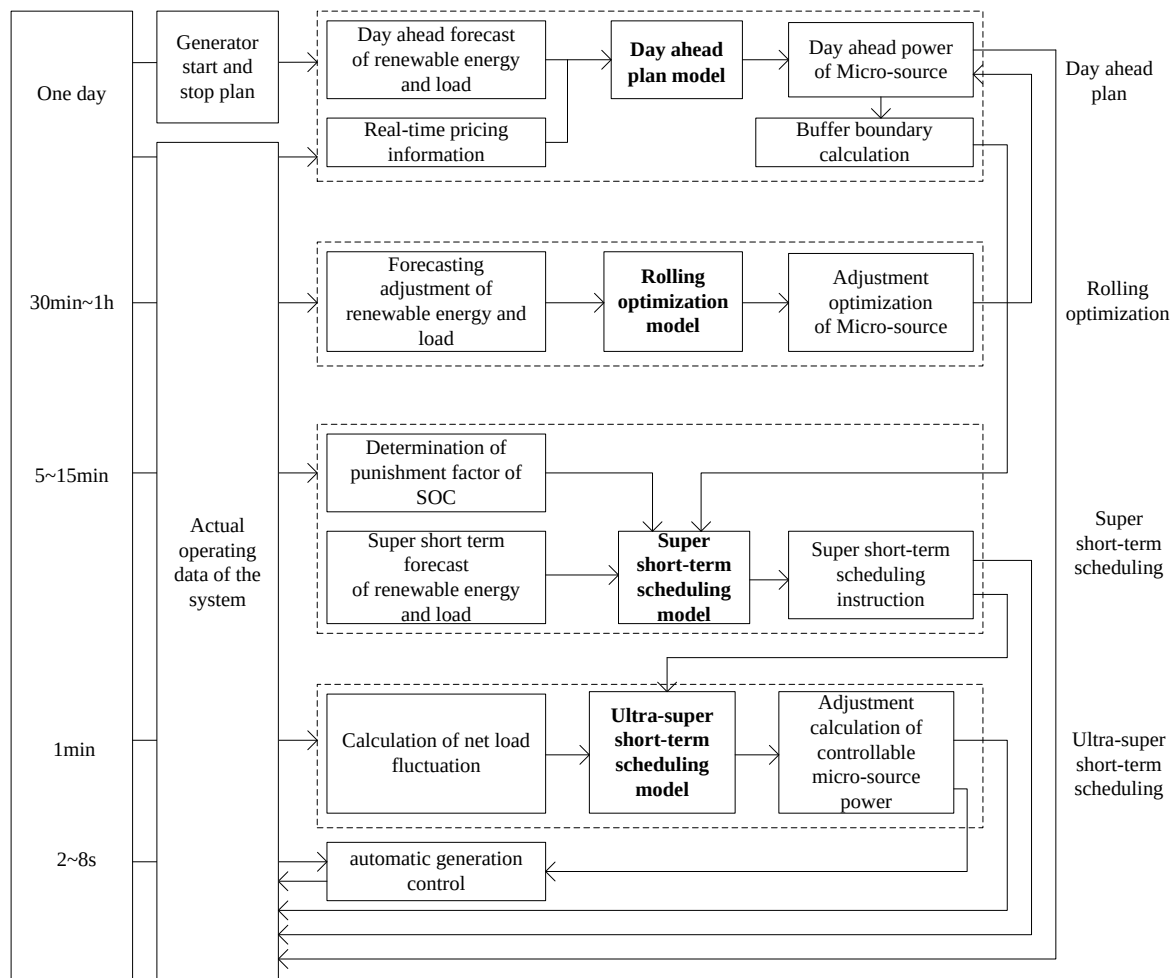
Domestic and foreign integrated energy system demonstration projects usually take consumption of renewable energy and the efficient use of energy as target to solve the depletion crisis of fossil energy. Compared with foreign demonstration projects, it can be seen that there are still gaps in the following aspects in China. In terms of energy coordination technology, our current multi-energy coordination technology mainly relies on local CCHP, which is relatively independent of other forms of energy output. Energy management and control is usually realized in the form of a micro-grid, which is relatively small. Foreign demonstration projects have further explored new energy coordination technologies and equipment, such as the use of energy routers, to achieve coordinated optimization of different energy resources from a global perspective. Table1 shows difference of domestic and foreign demonstration projects.

Table 1. Difference of domestic and foreign demonstration projects.

Difference	Domestic	Foreign
Coordinated optimization objective	Only the lowest costs for energy operators is considered.	The best returns of all stakeholders are considered.
Energy control scope	It is relatively small scale in the form of micro-grid.	Energy routers are used to realize regional/cross-regional energy optimization.

4. Collaborative control of integrated energy system

4.1. Optimal scheduling method of multi-energy system based on multi-time scale

**Figure 1.** Optimal scheduling method of multi-energy system based on multi-time scale.

The multi-time scale time series of 'long time-short time-real time' is used to reduce the impact of prediction error on the operation economy and stability of the system. The multi-time scale time series of 'long time-short time-real time' will establish an optimization model and design an optimization algorithm for each time scale, to realize optimal scheduling and coordinate through the power curve among various time scales. Firstly, the long-time scale optimization scheduling model is established

and the long-term scale optimization scheduling result is calculated, based on the operational measurement information and the long-term prediction information of DG and load. Then the long-term scale optimization scheduling result is distributed to short-time scale optimal scheduling model. In the short-time scale prediction period, the long-term scale coordination optimization result corresponding to the time point is taken as the initial value, and the short-time scale optimization scheduling result is calculated with the model prediction control method for the rolling optimization. Finally, the short-time scale optimization target curve is sent to the real-time control to complete the instruction allocation and realize the collaborative optimization scheduling. Figure 1 shows the schematic diagram of optimal scheduling method of multi-energy system based on multi-time scale.

4.2. Collaborative control method of multi-energy system based on multi-agent system

The hierarchical control structure based on multi-agent system can be established in the integrated energy system [6]. On the spatial scale, the hierarchical control strategy of the system layer, node layer and equipment layer is adopted. The multi-level target curve is distributed from top to bottom and the multi-level scheduling capacity is uploaded from bottom to top to realize the multi-level energy coordinated optimization control of the whole network and meet the consumption of renewable energy. Figure 2 shows the schematic diagram of optimal scheduling method of multi-energy system based on multi-time scale.

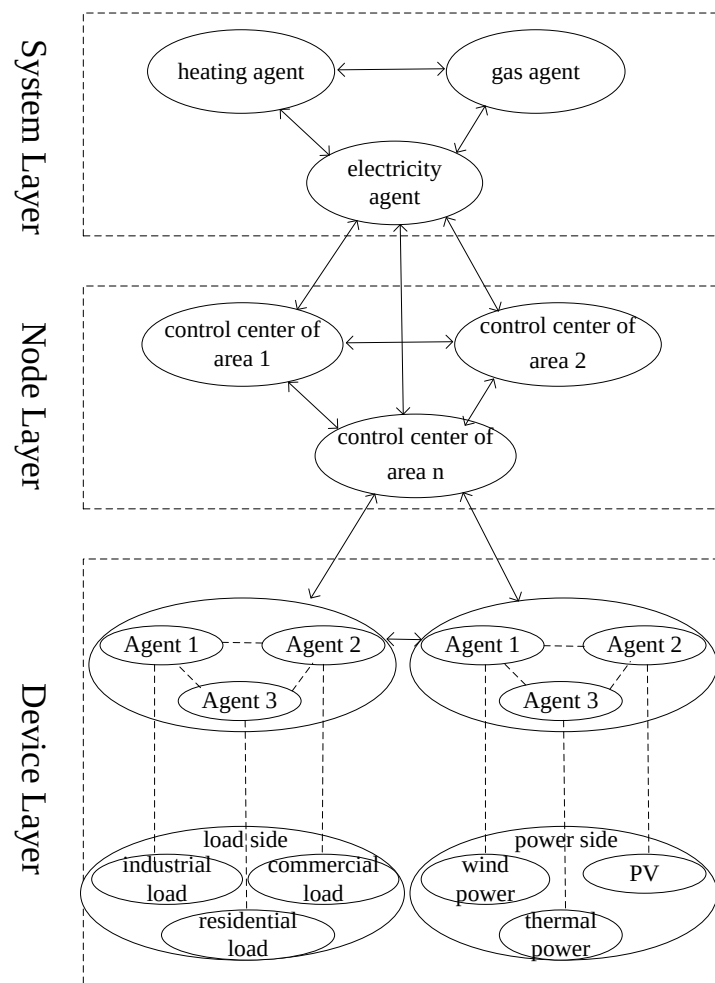


Figure 2. Optimal scheduling method of multi-energy system based on multi-time scale.

4.3. Key technologies to achieve collaborative control of integrated energy system

There is no comprehensive solution for power precision control and system stability issues in distributed coordination. A large number of random distributed energy accesses urgently require a more robust control structure and put forward higher requirements for communication reliability. In addition, because the communication topology is more complex and changeable, it requires a large communication and computing cost, and there are delays in data acquisition and transmission of distributed devices and primary networks. At present, only coordinated control under short-term or super short-term time mechanism has been carried out. With the development of information technology, research on quasi-real-time coordinated control technology to realize real-time interaction of multiple energy sources can be a future research direction.

Current energy systems can be plug-and-play for passive loads [7], while plug-and-play of sources (physical devices or systems such as micro-grid) is still not implemented. In order to realize the plug-and-play of distributed energy, we must first ensure the security and stability of the energy network. In addition, we need to study the following content: (1) Standard interface and protocol for plug-and-play of energy and information; (2) The self-organization and management of distributed devices, including the automatic sensing and identification of devices, the generation and assembly of equipment models, automatic communication, system-level collaborative management, etc. (3) The device itself realizes autonomous control to reduce the adverse impact on the system. The development of technologies such as energy routers, energy hubs, micro-grid, agents, clusters, and virtual power plants provides an effective means for plug-and-play of devices. The development of control technologies such as hierarchical control, distributed control, and peer-to-peer control will support open peer access.

5. Analysis of development factors of integrated energy system

The main factors influencing the development of integrated energy system include national policy support and the development of multi-energy system technology.

Energy issues cover a wide range of energy supply systems, including oil, natural gas, coal, electricity and other energy supply systems, and its terminal energy-using units are spread across all sectors of society, each component, and ultimately related to each member of society. Therefore, in order to ensure the safety and sustainable development of the social energy supply system, it is necessary to coordinate at the national level. The technical innovation of integrated energy system is an important basis for the realization of business model, while related policy system is an important guarantee for the realization of business model. The success of the business model needs to be tested by the market. Similarly, a mature business model requires constant practice and experience in a market environment. The business model not only needs the spontaneous creation of various commercial entities in the market, but also needs the guidance of relevant policies. It is the responsibility of government departments to support the development of potential business models and to encourage business entities to improve and innovate existing business models. We can select existing successful or potential business models, increase capital investment in central and local governments, and support a number of enterprises with core competitiveness and mechanism innovation. We will reduce market and industry access, promote data openness and strengthen energy market supervision.

Multi-energy system control technology involves multi-disciplinary and cross-disciplinary research on cold, heat, electricity, gas, transportation, etc. It is necessary to continue in-depth research in basic theory, focusing on breakthroughs in multi-energy flow safety assessment and early warning, multi-energy flow optimization scheduling and control and other key technical difficulties, and form a multidisciplinary and complementary technical team combining production, teaching and research.

6. Conclusions

As to the integrated energy system, the domestic and foreign application of the integrated energy system demonstration project is analyzed in this paper, and the differences and gap between the domestic and foreign demonstration applications is pointed out. Two technical routes for achieving

integrated energy coordinated control are proposed. The factors affecting the development of integrated energy system are analyzed, which can promote the development of integrated energy systems.

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