Prospect of Typical Application of Integrated Energy System

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Abstract. Integrated energy system can break the pattern of unconnected and independent between traditional energy systems, which is of great significance in realizing the integration of multiple energy sources and promoting the efficient utilization of energy. This paper first introduces the concept of integrated energy system, and then according to the characteristics of integrated energy system in planning, design and operation optimization, summarizes the three-level application scenarios applicable to different spatial scales, and introduces some typical application scenarios in detail. At the same time, according to the existing integrated energy system demonstration projects, the application theory of specific scenarios is extended. Finally, combined with the national conditions and energy development status of China, the problems and development direction of the future development of the integrated energy system are proposed, and some suggestions and ideas are given for the energy utilization and planning and design, so as to provide reference for the follow-up research.

1. Introduction
Energy is an important basic resource for the development of human society. With the rapid development of the world economy, the problems in the process of energy use are gradually exposed. The problem of the decrease of non-renewable energy and the low utilization efficiency of energy is becoming increasingly serious. The traditional energy use mode has been unable to meet the development needs of the future society. How to ensure the sustainable utilization of energy has become the focus of attention in the world today [1]. At present, most researches focus on improving the energy structure, promoting the consumption of renewable energy and improving the comprehensive utilization efficiency of energy. The concepts of energy Internet [2] and integrated energy system (IES) [1] provide a new perspective and angle for solving energy problems, effectively drives the transformation and innovation among multiple fields, disciplines and dimensions [3], and helps to promote a new round of reform and development in the energy field.

Based on the application of integrated energy system, this paper briefly introduces the concept of integrated energy system and the research status at home and abroad. Then, according to the characteristics of the integrated energy system, the typical application scenarios of the integrated energy system are summarized and described in detail. At the same time, on this basis, the problems and solutions faced by the future development of the integrated energy system are analyzed and prospected, so as to provide reference for further in-depth research in the later period.

Research status of integrated energy system
2. Research status of integrated energy system

The concept of IES was first proposed in 2001. Its main goal is to promote the spread and application of distributed energy and increase the proportion of clean energy [4]. A typical characteristic of IES is that it has a variety of energy coupling characteristics. It breaks the existing mode in which each energy system operates independently and does not connect with each other. It can coordinate and cooperate all kinds of energy and make comprehensive use of all kinds of energy. At the same time, the use of energy is tilted from traditional energy to clean energy, realizing the interaction between supply and demand of the energy system, mutual coordination and complementary advantages. This has improved energy efficiency, with obvious low-carbon, ecological and economic benefits. It is the future direction and vision of energy development.

The research of integrated energy system has been paid much attention all over the world, and a lot of work has been done at home and abroad.

Foreign research on IES started earlier, especially in the application of more mature. As an energy-deficient country, Japan has made a deep research on the application of integrated energy system. Its most typical application is Kashiwanoha Smart City, which based on the concept of comprehensive energy system, has built a smart city integrating smart energy, smart transportation, smart water, smart health care and smart agriculture [5]. Based on relevant theoretical research, Hammarby City in Germany integrates the treatment of urban water resources, various distributed energy resources, household garbage and other resources into one system, realizing sustainable urban life in an integrated way, which is of great significance to the sustainable development of energy [6-7]. Manchester City has developed and applied a comprehensive energy system integrating electricity, heat, gas and water [4].

Domestic scholars have also done a lot of research on the integrated energy system. The paper [8] points out that the difference of "quantity" and "quality" should be paid attention to in the operation process of multi-energy flow system. Exergy analysis was used by the author to analyze the economy and energy saving of the system operation process, and the optimal operation strategy of economic energy saving of IES was obtained. The article [9] pointed out that differences in quantity and quality of different energies should be taken into account as the basis of energy system planning, and proposed a five-level energy hub model based on exergy efficiency analysis for the analysis of system characteristics. This paper [10] elaborates on the low carbon benefits of the integrated energy system, points out its advantages in low carbon emissions, and gives the overall research framework of the low carbon system. The paper [11] proposes a multi-region integrated energy system collaborative planning model combining with the heat grid, which more intuitively shows the supply and demand complementarity among various energy systems. In addition to theoretical research, relevant demonstration projects have been established in China, such as China-Singapore Tianjin Eco-City, which will be introduced in detail in the fourth part.

3. One Typical application scenarios

This part mainly summarizes and sorts out the application scenarios of IES. From the perspective of spatial scale, the system is divided into three levels: global integrated energy system, regional integrated energy system and local integrated energy system. The global comprehensive energy system, which is a typical trans-regional system, mainly refers to the comprehensive energy system built by cities with a large geographical range or urban agglomerations closely related to energy. Due to the complexity of the system structure and the particularity of the energy market, the system for such applications is difficult to be applied in the short term, so it will not be repeated here.

3.1. Regional integrated energy system

The regional integrated energy system is mainly used in the areas with limited regional scope. It includes all kinds of factory areas, all kinds of industrial parks (such as industrial parks, ecological parks, business parks, and life parks), many interconnected parks on the energy network, cities of average size, and so on. This part takes the factory-district-block-city as the main line and selects typical regional application scenarios to introduce.
1) Integrated energy systems for typical plant areas

Factory-oriented IES is mainly characterized by multi-coupling characteristics of the factory. This part takes typical plant areas containing Combined Cooling, Heating and Power (CCHP) systems and Power to Gas (P2G) systems as examples to introduce relevant information. The combination of CCHP and P2G system makes the coupling between different energy networks closer, and improves the comprehensive utilization efficiency of energy while meeting electricity, heat, cold, gas and other energy demands. In addition, the electric energy in the trough stage is converted into natural gas for indirect storage, which effectively reduces energy waste and has a strong energy-saving advantage. Fig. 1 shows the structural diagram of a typical integrated energy system in a factory with CCHP and P2G system.

![Fig. 1 Structure diagram of IES in typical plant area](image)

The advantages are listed below. The existing CCHP near the user side is utilized, and P2G system is arranged around the load in a small-scale and distributed manner to independently output all kinds of energy, so as to realize local supply of energy and reduce the transmission cost of all kinds of energy. It can also store the electric energy in the valley stage, which greatly improves the reliability, economy and stability of energy supply. The whole system has high energy efficiency, low emission of air pollutants, obvious low carbon benefits, good ecological benefits and social benefits, and is an efficient way of comprehensive utilization of energy. The energy in this type of system can be converted to each other, which can guarantee the uninterrupted supply of energy. It can be used in independent plant areas or places with high stability of power supply and diversified energy demands.

2) Micro-grid integrated energy system for ecological park

With the total amount of non-renewable energy declining and gradually exhausted, more and more people begin to turn to renewable energy. How to increase the development and utilization of renewable energy such as wind energy, light energy, geothermal energy and biomass energy has gradually become a research hotspot. The micro-grid multi-energy system for the ecological park is to integrate the input, conversion, output and control of various renewable energies into a single system, and realize the power balance of internal energy through the conversion and utilization of various energies, so as to meet the demands of various loads stably and reliably and realize the local consumption of renewable energy.

In this type of integrated energy system, the energy input of the system is mainly a variety of renewable energy in nature (wind energy, light energy, geothermal energy, biomass energy, and so on.) and the energy that can be recycled in the region (household waste, and others.). Taking all kinds of green energy as "source" and converting it into various forms of energy supply "charge" can realize the local consumption of renewable energy. It not only realizes the coupling and complementing of various energy flows, but also makes full use of renewable energy, and can operate independently. It is an ideal system with economic benefits, environmental benefits and social benefits.

3) Interconnected integrated energy systems

Interconnected integrated energy system is an important spatial manifestation of regional economic development and industrial adjustment and upgrading, as well as an important component unit of future energy system. This type of system is mainly oriented to scenes such as various industrial parks, science
and technology parks, commercial complexes, life parks, and so on, and is mainly manifested as the interconnection and intercommunication of various parks. The main components of the interconnected integrated energy system include a variety of single integrated energy systems, transmission systems, control systems, energy storage systems. The structure diagram of the system is shown in Fig. 2.

![Fig. 2 Structure diagram of IES interconnection](image)

The interconnected integrated energy system centralizes the management and control of each single integrated energy system through control management center. When the energy in a single IES is not consumed in a timely manner within the region or cannot meet the needs within the region, the interconnected system can realize trans-regional transfer and consumption through the public transmission network and the energy storage system [12], so as to realize the coordination and interaction among energy systems. This can effectively avoid the waste of energy, realize the complementation of various energies among regions, promote the full consumption and utilization of renewable energy, and greatly improve the overall energy utilization efficiency. As various parks generally have convenient hardware infrastructure, as well as multi-type energy load demand, they have the advantages of building comprehensive energy system pilot, which is an important scene for the implementation and application of comprehensive energy system.

4) Integrated energy systems for new cities

With the continuous improvement of the urbanization level, cities have become the core units of energy supply and consumption with more and more types and quantities of energy demand. The new integrated energy city system is developed on the basis of the city, covering various integrated energy factory system, integrated energy park system, multi-park interconnection system, and so on. It includes various power plants, thermal power plants, gas distribution stations, heat exchange stations, energy hub stations, energy storage centers and so on.

Due to the diverse source charges, complex coupling characteristics and high fluctuation of energy use demand, the new urban energy system covers many research points. It includes comprehensive planning, overall scheduling, operation optimization, load forecasting, market trading, security analysis. A feasible research idea is to start with the topological characteristics of the integrated energy system, establish the topological description model and planning model of the regional integrated energy system based on energy flow balance, and provide reference for the construction and rational layout of the integrated energy city in the future. The existing urban energy system planning is mainly aimed at the newly built system, but the future comprehensive energy city is more about the transformation of the existing city, so it is also crucial to explore the urban planning scheme applied in different scenarios.

3.2. Local integrated energy system

To build a local integrated energy system within a small span is to integrate all the energy networks, such as electricity, gas, heat, cold, water and transportation, into the local energy system from the user's load side, so as to maximize the benefits of the local energy system.

1) Integrated energy systems for buildings

Buildings usually cover the whole floor of electricity, gas, heat and cold forms of energy. By coordinating and complementing the supply of the various energy forms mentioned above, an integrated energy system for buildings can be achieved. As a small and medium-sized building integrated energy
system, it contains less energy equipment, small capacity, single type, short distance of energy transmission line, low loss of line network, and is relatively simple in modeling and analysis. However, at the same time, there are many uncertain factors in this type of energy system, which are easily affected by the change of user load. For example, external environment, internal policy and so on all have an important impact on the way of building energy use.

Some scholars have carried out research on building integrated energy system. This paper [13] takes buildings with new energy utilization including renewable energy utilization as the entry point, establishes an energy hub model including photovoltaic power generation and other energy conversion forms, and conducts an analysis on the research on optimal operation and scheduling of energy. This paper [14] takes into account the characteristics of buildings, such as high uncertainty and vulnerable energy use, and builds an energy hub consisting of CCHP and plug-in hybrid electric vehicle, and studies the economic operation of the building grade integrated energy system under uncertainties.

2) Integrated energy systems for homes
Traditionally, the energy needs of home users have been obtained from the public network of various energy systems. However, with the emergence of IES and the development and popularization of various advanced technologies, the investment in building small integrated energy systems is within the range of affordability. Integrated energy systems based on household users are gradually emerging and are expected to become a non-negligible unit in the energy structure in the future.

As the energy consumption load of a single family can be calculated and controlled, family users can make full use of local natural resources and build a comprehensive family energy system with family housing as the core. Photovoltaic panel or thin-film power generation technology can be used for the supply of electric energy, and electric vehicles can be introduced to integrate intelligent transportation into the system at the same time. Heat is obtained from light and used for the supply of heat to the home; The use of biogas can be realized by recycling household garbage and excreta and building a biogas digester. At the same time, with the help of advanced energy storage technology, the excess energy in the local system, which cannot be consumed in time, is stored on the spot and set aside for future use. It is not difficult to find that the integrated energy system based on the family unit can be completely self-sufficient in all kinds of energy if it can be properly arranged and arranged. At the same time, if allowed, local users can also sell extra energy to nearby users to obtain certain economic benefits.

This kind of system is characterized by small convenience, strong controllability, benefits after the system is built, and high short-term benefits, especially suitable for remote families with inconvenient access to public network.

4. Typical applications and research prospects

4.1. Typical applications
The park-oriented system in the regional integrated energy system has the advantages of moderate scale, strong operability and so on, and has more advantages in the field application. The China-Singapore Tianjin Eco-City, located in Binhai New Area of Tianjin, has already had the prototype of comprehensive energy system, although it started early. With low-carbon industry as the core and energy utilization as the focus, the eco-city adopts an energy utilization mode that integrates conventional energy and renewable energy, centralized energy and distributed energy to ensure safe and reliable energy supply. The structure of energy supply is shown in Fig. 3 below. The eco-city makes effective use of renewable energy such as solar energy, wind energy, geothermal energy and biogas, and strengthens the utilization of energy step by step through various new energy conversion technologies, thus building a diversified, healthy and efficient energy system. It is a typical comprehensive energy application scenario.
In order to solve the problems existing in the traditional energy supply mode, Datong Energy Revolution Science and Technology Innovation Park puts forward the solutions of multi-energy supply, multi-energy coordination and complementation, and fine operation and maintenance of energy, and is committed to creating a new energy development format featuring smart energy, fine operation and maintenance, and building energy conservation. Demonstration area set office, scientific research, new energy industry, comprehensive commercial services in one. Through the accurate analysis of the load characteristics of the park, the renewable energy can be accessed and consumed nearby, and the green electricity such as scenery can be sold, which can not only improve the energy utilization rate, but also reduce the energy operation cost, thus achieving zero carbon and wisdom. It is a typical application scenario of comprehensive energy. Various forms of energy utilization in the Science and Innovation Park are shown in Fig. 4 below.

As can be seen from Figure 4, the park is equipped with a variety of energy utilization equipment to maximize the efficient utilization of renewable energy within the park. At the same time, phase change energy storage, electrical energy storage, hydrogen energy utilization and other ways to achieve energy storage and utilization. Electric vehicles, DC equipment and other more abundant use of energy forms. Each energy link is coordinated and distributed through the comprehensive energy service center, and the cloud computing big data service center provides guarantee for multiple information exchanges in the park, so as to realize the "smart" park. While the park is self-sufficient, the surplus energy is traded
in the market with the surrounding schools and houses, so that the normal operation of the park can be guaranteed and part of the economic benefits can be obtained.

4.2. Discussion on development Direction
To realize the practical application and development of the integrated energy system is confronted with difficulties and obstacles in policy and technology. In accordance with the main line of global, regional and local, this part elaborates relevant issues and development direction from the national, regional and local levels respectively.

1) National level
For a long time, large energy systems in China, such as electric power system, natural gas system and thermal system, have been planned, operated and managed separately, and there are long-term barriers between industries. To realize multi-energy complementary interconnection, each energy system has an inseparable relationship and requires the active participation of each energy system. The state should issue relevant laws and regulations to resolve the inherent difficulties from the policy. To coordinate all aspects involved in the energy system, break down industry barriers, encourage, support and guide all energy links to participate in the development of the comprehensive energy system, and promote the construction of a new energy interconnection system. Set up functional departments of energy management when necessary, such as integrated energy service company or energy management center. The purpose is to balance the interests among all subjects, realize the maximization of interests, and organize all industries to actively and orderly participate in the development of comprehensive energy system at the national level.

2) Regional level
Our country is broad in territory, each place has this area unique characteristic. Therefore, each region should combine the local actual situation, deeply explore the energy supply characteristics, transmission forms and load response modes within the region, promote territorial management, seek the mode of energy supply and transport suitable for the region, and actively build a comprehensive energy system with local characteristics and characteristics. In addition, at present, the independent operation and planning of pipelines of various energy systems lead to low efficiency, so the centralized planning of multiple energy systems is imperative. Multiple constraints among interconnected systems should be taken into account, and the overall planning and coordination of regional integrated energy systems should be carried out to obtain the optimal allocation mode of operation of multiple energy systems.

3) Local level
A large number of loads are gathered in the local system, and energy-using equipment is centralized, with diverse energy-using demands, including electricity, heat, cooling, gas and other energy demands. Boiler, large machinery, air conditioning and other high-power equipment, electric vehicles and another uncertain load. It is necessary to strengthen the real-time prediction and timely supervision of local load, make local energy use plans by using big data, establish a comprehensive demand response mechanism, strengthen the coordination and scheduling among load users, fully develop new energy technologies, and promote the stable development of local energy use.

In addition, extensive participation should be guided and typical demonstration sites and test sites should be established. As a result of the integrated energy system is housed in the coupled system, its mechanism is complex, the space and time scale is not unified, more uncertain factors lead to the modeling of complex system, such as inaccurate model analysis, to establish the typical demonstration project or area, key technology research and field test, and explore from reality system operation mechanism and operation mode, for a wider range of research and promotion.

4.3. Development trends and recommendations
Based on the foregoing, this part proposes the development ideas for the key links in the future development of integrated energy systems.

1) The use of energy
In terms of energy supply, we should fully exploit the advantages of renewable energy, vigorously develop renewable energy and build a coordinated and reliable energy supply system. Compared with traditional energy sources, renewable energy sources such as photovoltaic, wind power and geothermal energy have incomparable advantages. There are many kinds of resources, all from the nature, the amount of resources far more than traditional energy, energy cost is low, clean and pollution-free, huge development potential. Photovoltaic power generation, wind power generation and other forms of energy utilization have become increasingly mature. We should constantly explore new forms of energy utilization, diversify the development of renewable energy sources, and build a comprehensive energy structure tailored to local conditions.

In the construction of energy network, the hybrid multi-energy network system centering on electric network should be built. As a new generation of energy system, integrated energy system is an energy system with electric energy as the center, power grid as the backbone and power consumption as the basis. With the high proportion of renewable energy access and the continuous development of DC loads such as electric vehicles and DC equipment, the application and development trend of DC technology will become more prominent. Compared with AC power grid, DC power grid has the characteristics of stable operation and flexible control, and DC power supply equipment, DC electrical equipment and energy storage equipment are uniformly connected to the network, which can avoid DC-AC-DC multistage conversion and significantly reduce energy loss. Therefore, it is necessary to vigorously promote the construction of smart power grid, rely on the existing large power grid and distribution network facilities, focus on the development of DC power grid, build a hybrid network, and extend the energy network of the whole integrated energy system on this basis.

2) Planning and layout

In the hierarchical planning of integrated energy system, energy stations and energy pipe networks are important links. The energy station is the key hub to coordinate the energy flow in the region, adjacent regions and upper and lower regions. The pipe network is the key guarantee for timely and reliable energy transmission.

The site selection of energy stations refers to ensuring the maximum energy supply radiation area of energy stations and obtaining the optimal number and location distribution of energy stations on the premise of minimizing various investment and operation costs. Regarding the site selection of energy stations, two models can be referred: the spider model and the honeycomb model, which are respectively shown in Fig. 5 (a) and (b). The cobweb model is mainly applied to economic analysis, but the model itself describes a dynamic changing scene, which is consistent with the dynamic changing characteristics of the energy system, and planning research can be carried out on the dynamic characteristics of the energy site. The cellular model is mainly applied to network information transmission. The cellular model is adopted in the site selection and capacity allocation of energy stations, which can avoid the repeated waste of limited resources, improve the energy exchange between sites, and contribute to the stable flow of energy flow.

Network planning is mainly based on the flow form of energy, transmission loss, delay characteristics and so on to get the optimal layout. The most common pipe network layout is the radial structure, as shown in Fig. 6 (a). In this structure, the upper and lower levels of the system conduct energy interaction through the energy flow bus, and the bus is connected with distributed energy and energy storage devices.
The structure is simple and easy to configure, but the reliability is low. In order to improve reliability, a tree structure with multiple bus layers can be adopted to reliably ensure multi-terminal energy supply, as shown in Fig. 6 (b).

![Fig. 6 The flow form of energy](image)

5. Conclusion
In this paper, the typical application of integrated energy system scenario was discussed, and put forward the global scope of the integrated energy system, the integrated energy system as well as the local scope of area of integrated energy system, and a typical application scenario for detail, and discusses the future development direction and key issues, and try to give the key link of development ideas, so as to provide reference for subsequent research.

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