MICROGRIDS FOR ELECTRICITY GENERATION IN CHINA

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YANG DECHANG

DECEMBER 2, 2020

I. INTRODUCTION

In this Special Report, Yang Dechang summarizes current research on and deployment of microgrids in China, including an overview of the history of microgrids in China, two examples of microgrid projects currently operating in China (Dongao Island and Sino Singapore Tianjin Eco-City), progress on regulation and policies related to integration of microgrids with central grids, and key evolving microgrid technologies.

A summary of this report follows. A downloadable PDF file (0.8 MB) of the full report is **here.**

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Banner image: The Dongao Island megawatt-level independent smart microgrid project was China's first megawatt-level microgrid system with complementary wind, solar, diesel, and energy storage, and was also China's first commercial-run island smart microgrid system. The power supply is flexible and especially suitable for island and remote areas. The diesel power generation in the system has been greatly improved by the addition of the other system components, reducing power generation cost and island pollution. Image from here.

II. NAPSNET SPECIAL REPORT BY YANG DECHANG

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Summary

Microgrids have attracted attention both in academia and industry in recent years because they can effectively utilize the distributed renewable energy resources to enhance the reliability of distribution networks. As an important part of a strong smart grid, microgrids can efficiently integrate various distributed electricity sources, increase the penetration rate of renewable energy, and make up for the shortcomings of centralized power supplies in large grids. Due to the late start of China's microgrid development and the relatively immature microgrid technologies and standards, as well as being in the early stages of promoting microgrids, China's microgrid deployment is still largely in the experimental and exploratory stage. In view of this, this paper introduces the definition, types, development history and trends of China's microgrids, and provides examples of existing microgrid projects. Then, taking Dongao Island and Sino Singapore Tianjin Eco City installations as examples, the development of microgrids in China is introduced in detail. After considering the grid connection policy of my country's microgrid, the process of development and innovation of key technologies related to microgrids in China are studied. Finally, this paper concludes with a summary and a forecast of the future development trend of microgrids in China based on a review of the current development status of and existing policies affecting microgrids, which provides guidance for further research.

1 Introduction

1.1 Brief Summary of the Status and Deployment Trends of Microgrids (MG) in China

The harnessing of energy resources is the material basis for maintaining the progress of human civilization and of social and economic development. As a resource-rich country, China has various forms of energy resources, but its energy supply structure and the geographical distribution of key resources are not satisfactory. At present, there are many problems in China’s energy sector, with two issues being the most important: The first issue is that China's resources are dominated by coal and water (hydroelectric power), with oil being mainly imported in recent years, and natural gas being relatively scarce. The per capita resource in China is far below the world average level, which is backward compared with most developed countries. The second feature is that the distribution of resources does not match the pattern of resource demand. China's resources are mainly located in the west, while the main electricity load centers (and centers of energy demand generally) are in the east. In addition, with the rapid development of domestic industries, the large-scale development and utilization of fossil energy has promoted the progress of building the domestic civilization and economy, but it has also brought about significant problems such as resource shortages, environmental pollution, climate change, and impacts on people's health. Promoting an energy transition to renewable and clean fuels is the only way to realize China's sustainable development. As a new form of comprehensive energy utilization, the use of microgrids can provide comprehensive energy management compared with traditional distributed energy systems, attributes that have attracted the attention of many domestic scholars and research institutions.[1]Microgrids refers to small power generation and distribution systems composed of distributed generators, energy storage devices, energy conversion devices, related loads, monitoring devices and protective devices. Microgrids are autonomous systems that can realize self-control, protection and management. They can run in conjunction with external power grids or in isolation. Microgrids are powerful supplements to large power grids and are an important part of the smart grid field. Microgrids haves a wide range of application prospects in industrial and commercial areas, urban areas and remote areas.[2] Compared with foreign countries, research on microgrids in China started late, mainly in three respects: model establishment, control strategies, and stability analysis. In 2004, China began to carry out research on the concept of microgrids as proposed by the United States. This research has been based on the connection of distributed generation to large electrical grids via AC (alternating current) microgrids and the impacts of microgrids on large grids. With the continuous deepening of research, experience has been accumulated in China in the planning and design, operation control and energy management of AC microgrids. In more recent years, Chinese scholars began to simulate DC (direct current) microgrids. From 2009 to 2016, research on DC microgrids in China has gradually involved many different aspects, such as the study of DC microgrid power electronic converters, DC circuit breakers, and other key equipment, as well as operation control technology, protection, and energy management.[3]

1.2 China’s Current and Planned Policies Regarding MG

At present, the development of domestic microgrids in China is at the stage of building projects as demonstrations for commercial operation. There are still many challenges in the practical application of microgrids in China. Policies, technologies and economics are the three main factors restricting the further development of microgrids.

First, based on an analysis of policy factors, China is paying more and more attention to the development of new energy sources and the efficient use of energy, and the policy orientation towards these topics continues to be favorable. Current electric power regulations, however, are in conflict in some ways with the construction and operation modes of microgrids. The State's policies on microgrid subsidies and on-grid tariffs are still unclear as of this writing. There is also a lack of laws and regulations related to microgrids, which has become one of the main obstacles to future microgrid development.

Secondly, from a technical perspective, some microgrid technologies are not fully mature in China, and key technologies need to be further studied and verified by experimentation. Research into the performance of application equipment such as energy storage systems, operation control systems, microgrid protection systems and energy management systems needs to be further strengthened. The mechanisms and analysis methods of microgrid stability problems need to be studied in depth. New ideas for the protection of microgrids need to be explores based on the unique characteristics of microgrids, as well as borrowing concepts developed in research into protection methods and technologies for central electrical grids. Planning methods for microgrids needs continuous improvement. In terms of microgrid planning and design, equipment manufacturing, and construction, so far there have been no unified and complete technical standards and management norms at the national level in China.

Finally, from an economic point of view, the cost of distributed power sources such as wind turbines, photovoltaics, and energy storage are still relatively high, though in each case costs have been declining rapidly. The investments required for the construction of microgrids are relatively large, it is difficult to recover costs in the short term, and there is as yet no competitive market for microgrid electricity. The key tasks to promote the development of microgrids in China are therefore to further develop technologies and reduce the costs of related equipment. Only in this way can the economics of microgrids be improved, and the deployment microgrids in China can be gradually transformed into a policy-led model. This improvement in technologies can improve the economics of microgrids, and can transformation of China's microgrids policies.

As technologies mature, the cost of renewable energy is gradually decreasing. The increasing demand for renewable energy, the development of the energy storage industry, and continuous increases in the price of fossil energy will encourage the development of microgrids so that they account for an increasing proportion of electricity production. With these ongoing changes, China's microgrid market will enter a stage of rapid growth.[4]

1.3 Map to Remainder of Paper

In the remainder of this paper, First, in section 2, the definition, types, development history and trends of China's microgrids are introduced, and China's existing microgrid projects are described from multiple perspectives such as geographic locations, industry uses, and operational modes. In section 3, taking Dongao Island and Sino-Singapore Tianjin Eco-City, two typical independent smart microgrid projects in China, as examples, three aspects of the development of microgrids in China are introduced in detail, namely project background, project structure and project effects. Section 4 describes current and recent agreements on the integration of China's microgrids with local and central power grids are studied from the national and industry levels. Section 5 summarizes the development and innovation of microgrid technologies in China such as controlled energy storage, intelligent protection, power electronics, and renewable energy. The final section of this paper, section 6, summarizes and forecasts future development trend of China's microgrids based on the current status and policies of existing microgrids, and provides suggested directions for subsequent research.

2 Definition, History of Development, and Types of Mini- and Microgrids in China

2.1 Definition of Mini- and Micro-grids in General

The term “microgrid” refers to a small power generation and distribution system composed of distributed generators, energy storage devices, energy conversion devices, related loads, monitoring devices and protective devices. It is an autonomous system that can realize self-control, protection and management. It can run in conjunction with the external power grid or in isolation. From the structural point of view, microgrid can usually be divided into four aspects: distributed micro--, energy management system, transmission and distribution system and load. The structure of microgrids is shown in Figure 1.

Microgrids generally have four basic features:

(1) “Micro”, microgrid voltage levels are generally below 10 kV (kilovolts), the system scale is generally MW (megawatt) level or smaller, the grid is connected with end users, and the electric energy provided in the microgrid is typically used locally.

(2) “Cleaning”, the distributed power supply inside a microgrid is mainly clean energy, or uses power generation with the goal of comprehensive utilization of energy.

(3) “Autonomous”, the internal power of a microgrid can achieve full or partial self-balancing of electricity demand and supply.

(4) “Friendly”, microgrids can reduce the impact of large-scale distributed power access on the central or main power grid, provide users with high-quality and reliable power, and achieve smooth switching between central-grid-connected and off-grid modes.

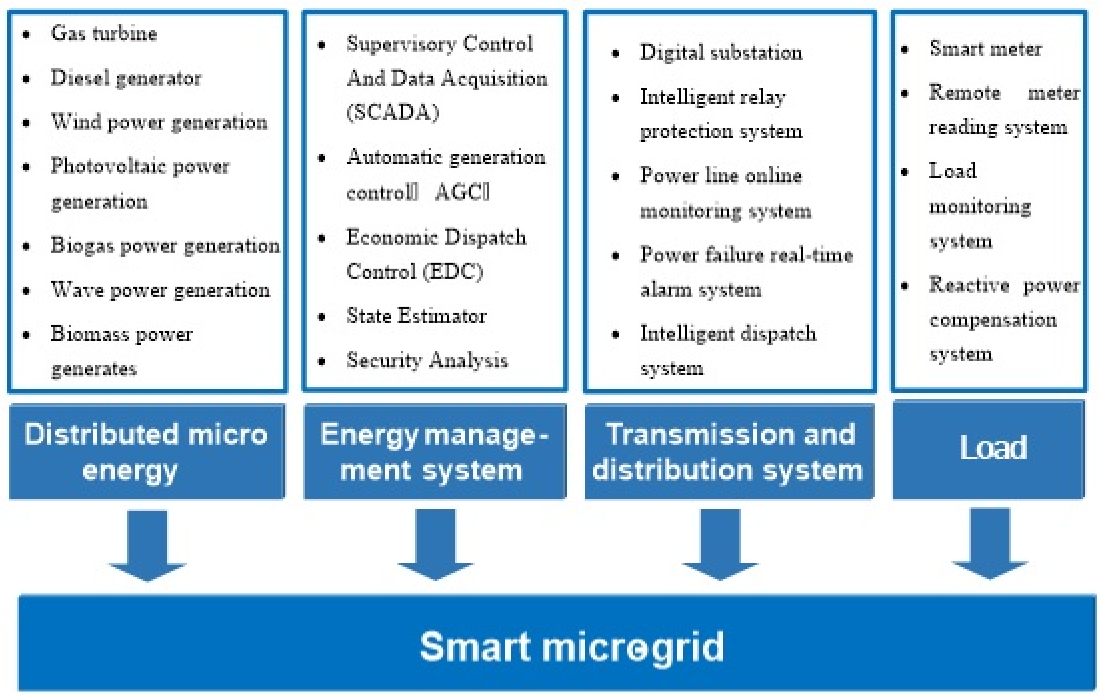

Figure 1: Structure of Microgrids

2.2 Types of Microgrids

The Operation modes of microgrids include grid-connected mode, off-grid mode, and the conversion process mode between the two. The characteristics of each operational mode are shown in Table 1.

Table 1: Operational Modes of Microgrids

operation mode	characteristic
Grid-connected mode	The micro-grid is connected to a large public power grid, and the micro-grid circuit breaker is closed to exchange electrical energy with the distribution system of the main grid. Distributed generation is connected to the grid to generate electricity, and the energy storage system can perform charging and discharging operations in grid-connected mode.
Off-grid mode	This is also known as island operation. The microgrid is disconnected from the distribution system of main grid when the grid fails or as is required by operational plans. Off-grid mode is an operational mode composed of distributed power sources, energy storage devices, and loads.
Microgrid switching state	The microgrid is switched from grid-connected mode to off-grid mode, or from off-grid mode to grid-connected mode. The switching between the two must be smooth and fast.

Operational modes for microgrids are grid-connected and island micro-grid modes.

（1）Grid-connected microgrid

These microgrids can run in either grid-connected or off-grid modes. Generally, grid-connected systems are used for public facilities such as parks, buildings, and hospitals. The use of microgrids allow local consumption of clean energy and ensure that important loads are not affected by power outages on external grids.

（2）Island microgrid

Microgrids can also run in only off-grid mode. This approach is generally used in areas without available main power grids such as areas at high altitude, islands, border defense areas, and uninhabited areas. By constructing a micro-grid based on new energy generation such as wind and solar, plus electricity storage, the problems associated with use of expensive diesel power alone, often with high noise levels and insufficient power supply capacity, can be solved.[5]

2.3 History and Trends of Microgrid Development in China

China's development of microgrids has started relatively late compared with developed countries such as Europe and the United States, but the Chinese government attaches great importance to microgrid development. The development of China's microgrids can be divided into three stages according to development speed and scale. The three stages are as follows.

- The first stage (2004~2009)

In this stage, China began to explore the development of microgrids, but the number of projects was small. Micro-grids were not under large-scale development.

Around 2004, some universities and research institutes began the process of microgrid technology research in China.

In September 2005, Tsinghua University signed a cooperative research agreement with Liaoning High Tech Energy Group Co., Ltd., establishing China's first microgrid Research Institute.

In 2006, Tsinghua University worked with the State Key Laboratory of Power Generation Equipment Control and Simulation to build a microgrid experimental platform. At the same time, Tsinghua University and Xuji Group Co., Ltd. cooperated to build a microgrid simulation platform, and carried out research on the safety and stability analysis of microgrid operations, developing general models of micropower power electronic interfaces, and an integrated control model for microgrids.

In 2007, Hefei University of Technology and the University of New Brunswick in Canada jointly launched research on the integration and control technology of distributed multi-energy complementary energy microgrid power supply systems. The partners built a demonstration, independent microgrid system with a power generation capacity of 200 kW (kilowatts) on the campus of Hefei University of Technology, which mainly uses solar and wind energy to generate electricity. In the same year, the State began to pay attention to research on microgrid technologies. At that point, the State included research on microgrid technologies in the "863 Program", "973 Program" and other national high-tech projects, which promoted the application of microgrids in China.

In October 2008, Hangzhou Dianzi University cooperated with the New Energy Industry Technology Development Organization of Japan to build a 240 kW interconnected microgrid demonstration system at the school’s Xiasha campus as a part of the "Advanced and Stable Grid-connected Photovoltaic Power Generation Microgrid System International Cooperative Empirical Research" project. The microgrid was at the time the only experimental microgrid with a photovoltaic power generation ratio of 50% in the world.

In 2009, as China's research on microgrid technology continued to deepen and the technology became more mature, central and local governments at all levels paid more attention to promoting the application and development of microgrids, and the construction of microgrids was repeatedly mentioned in energy policy documents . The development of China's microgrids officially kicked off at that time.

- The second stage (2010~2015)

In this stage, during the Twelfth Five-Year Plan period, the key task of smart grid advancement was to develop large-scale intermittent new energy power grid-connected technologies and produce breakthroughs in the core key technologies needed for smart grids such as large-scale intermittent new energy power grids and energy storage. As the country increased its investment in smart grids, microgrids encountered good development opportunities as components of smart grids.

In September 2010, the Ministry of Finance, the Ministry of Science and Technology, the Ministry of Housing and Urban-Rural Development, and the National Energy Administration jointly issued the "Notice on Strengthening the Construction and Management of Golden Sun Demonstration Projects and Solar Photovoltaic Building Application Demonstration Projects", which proposed to strengthen the construction of microgrids and provide pilot projects on the construction of systems for microgrid operational management . Driven by these policies, some companies started the construction of microgrid demonstration projects.

In March 2012, the Energy Administration commissioned the Institute of Electrical Engineering of the Chinese Academy of Sciences, Tianjin University and other scientific research institutions to carry out “Research on the development strategy of China's microgrid during the 12th Five Year Plan”. It was proposed to build 30 microgrid demonstration projects nationwide during the Twelfth

Five-Year Plan period.

In July 2012, the National Development and Reform Commission (NDRC) issued the "Twelfth Five-Year Plan for Renewable Energy Development" and the "Twelfth Five-Year Plan for Solar Power Development", which clearly proposed the construction of 30 new energy microgrid demonstration projects by the end of 2015.

In August 2012, there were 16 microgrid pilot projects in China. Among them, 11 operated at 380 Volts (V), 4 were 10 kV, 11 had generation capacities smaller than 1 MW, and 4 had capacities below 5 MW, all equipped with energy storage systems. But the self-balancing ability of these pilot projects were generally insufficient.

Since September 2013, China has officially launched the construction of 100 "New Energy Demonstration Cities", and microgrids are seeing favorable development opportunities.

By December 2015, China had completed more than 60 microgrid demonstration projects, far exceeding the National Energy Administration's plan to build 30 microgrid demonstration projects during the Twelfth Five-Year Plan period.

With the construction of smart grids, the average growth rate of China's microgrid market was about 8% during the Twelfth Five-Year Plan period. In 2015, the installed capacity reached 17,000 kW, and the investment for these projects totaled about 3.18 billion yuan. Documents on microgrids and related topics were continuously by the State, such as "Renewable Energy Industry Development Guidance Catalog", and "National Medium and Long-term Science and Technology Development Plan Outline (2006-2020)". With the support of the "863 Program", the "973 Program", the "Golden Tianyang Project" and the Natural Science Fund, microgrid technologies have developed rapidly, and pilot projects have sprung up with their own characteristics.[6],[7] The growth in market size of China's microgrids from 2011 to 2015 is shown in Figure 2.

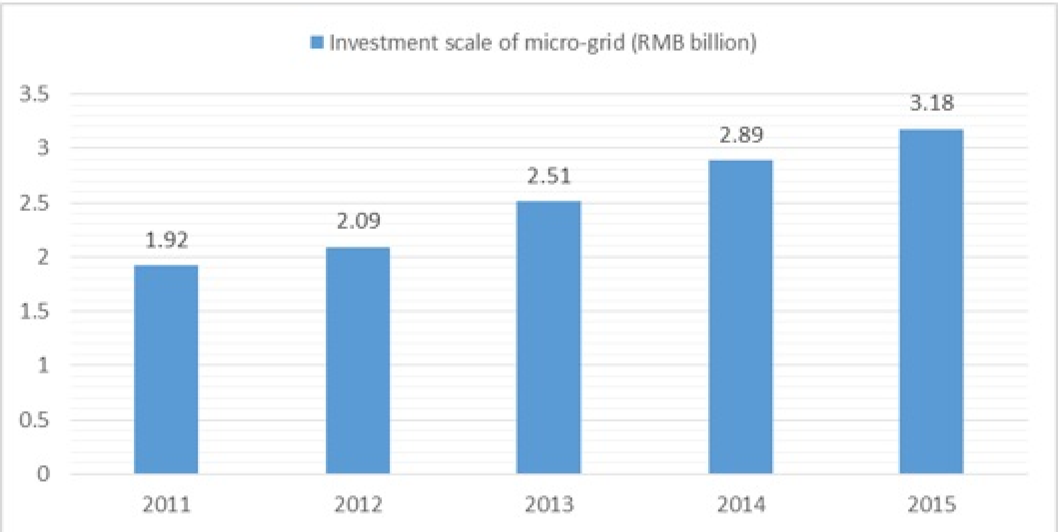

Figure 2: The Market Size of China's Microgrids from 2011 to 2015

At this stage, during the 13th Five-Year Plan period, pilot power reforms and related documents were issued. In particular, the "Power Generation Liberalization Plan" proposed that China should give priority to clean energy, ensure full purchases within the planned scope of clean energy deployment, and promote trans-provincial interconnected power market transactions. New energy power generation has undoubtedly become the biggest beneficiary of these policies, and as a result the microgrid development has entered a breakout period.

In 2016, the China Electricity Council organized and compiled the "13th Five-Year Plan for Standardization of the Electric Power Industry" to guide the standardization work arrangements in the power industry. The document includes a proposal to improve microgrid standards systems and to formulate technical standards for microgrid energy management systems, monitoring systems, security systems, and off-grid microgrids.

2017 was a milestone year in the history of China's microgrid development. In this year, there were three firsts with regard to microgrids: the first issuance of microgrid sales permits; the first batch release of lists of microgrid demonstration projects; and the first release of "Trial Measures for Microgrid Construction."

In April 2017, Xinhuanet announced that the Turpan New Energy Urban Microgrid Demonstration Project had obtained a power sales license, becoming the first microgrid in China to obtain a power business license. The significance of obtaining a power sales license is that the project company has the right to operate, manage and sell electricity in the microgrid area, and becomes a power sales company with the right to operate a distribution network.

In May 2017, the National Development and Reform Commission and the Energy Administration announced a list of 28 new energy microgrid demonstration projects. The list included four independent projects with a total of 899 MW of new photovoltaic installed capacity. In so doing, China announced a list of microgrid demonstration projects on a large scale for the first time. Due to the support of national policies and the maturity of conditions in the field of microgrids, the rapid expansion of the market was seen as coming rapidly.

In July 2017, the National Development and Reform Commission and the Energy Administration issued the "Trial Measures for Promoting the Construction of Grid-connected Microgrids", which has been the most important document in the field of microgrids by far. The document stipulates that new energy power generation projects operating within microgrids enjoy the renewable energy power generation subsidy policy prescribed by the state. This policy support promoted the rapid development of the microgrid industry.[8],[9]

As of the end of 2018, the number of microgrids installed in China was 35 (totaling 202 MW). China was at that time the world's second largest microgrid market after the United States. In addition, China had a 4.2 GW microgrid project in the process of preparation and construction at the end of 2018 in response to the government’s encouragement of the use of renewable energy in industrial parks. The number of USA and Chinese microgrid installations and their installed capacity as of the end of 2018 is shown in Figure 3.

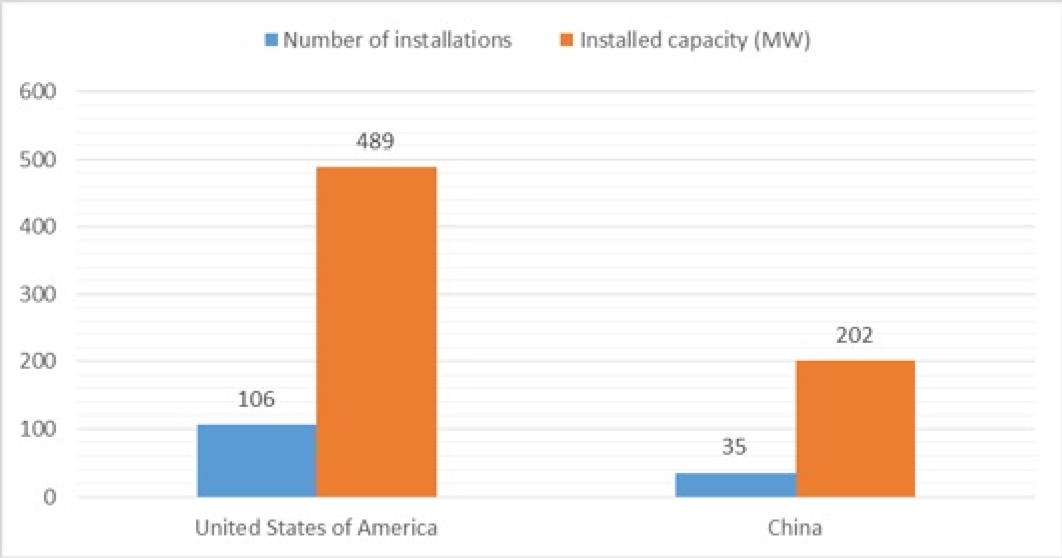

Figure 3: The Number of US and Chinese Microgrid Installations and their Installed Capacity in 2018

It is predicted that by 2020 China's distributed energy microgrid technology will reach the international advanced level. As domestic and foreign supply and demand conditions are difficult to balance in the short term, the microgrid industry has a strong market demand. The **"Internet Plus"** concept is being applied in the field of microgrid, bringing new development space for microgrid technologies. As a result, competition between traditional enterprises and Internet platforms is fierce, providing new growth space for the microgrid industry.

- The fourth stage (future)

China's future energy development needs to accomplish the transformation from a single energy system to a comprehensive energy system, realize the complementarity of multiple energy sources, and improve energy efficiency. The future development direction of microgrids in China will therefore be towards an energy system that integrates electricity, gas, water, and heat resources, achieves mutual coupling, and solves the problems of efficient energy utilization and peak regulation[10].[10] The growth in the proportion of China's clean energy consumption as a fraction of total energy consumption from 2009 to 2018 is shown in Figure 4.

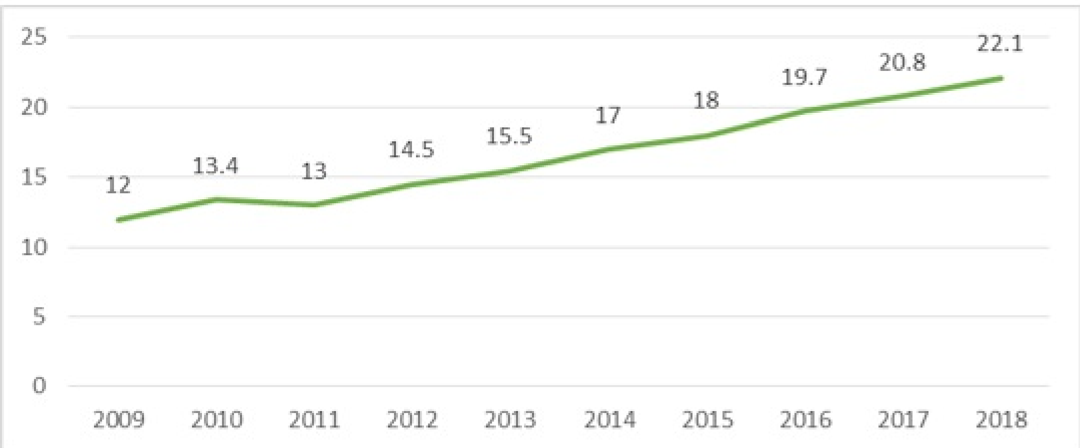

Figure 4: The Proportion of China's Clean Energy Consumption in Total Energy Consumption from 2009 to 2018 (percent)

Microgrids are the most effective application form of integrated energy. The coordinated optimization of multiple energy sources such as electricity, gas, and heat in a local area is the basis for comprehensive energy development. Microgrid technologies, coupled with Internet technologies, can realize the development of regional “energy Internets”. Microgrids can accept a high proportion of renewable energy and support users' flexible energy use and flexible transactions around energy sales and purchases. Figure 5 shows the market scale forecast for deployment of China's energy Internet in the future. It can be seen from the figure that the scale of the energy Internet market will continue to expand, and microgrids will also develop rapidly. It is estimated that China will build about 50 distributed energy microgrid demonstration projects by 2025, forming a distributed microgrid technology system, market system and management system. At that time, the technology will be advanced, the management will be on a scientific basis, and the mechanism of implementation will have been highly advanced.

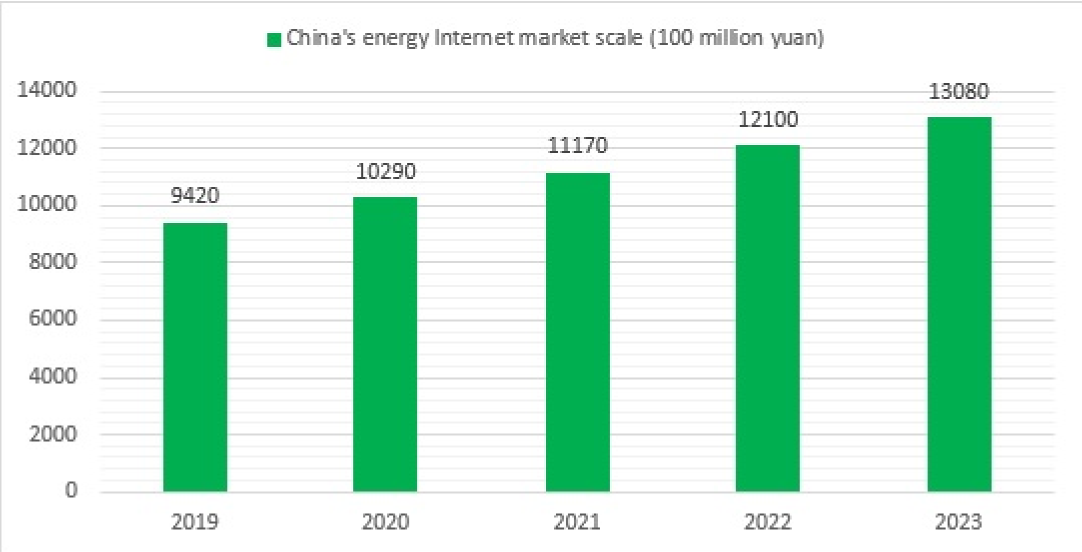

Figure 5: Forecast of China's Energy Internet Market Size from 2019 to 2023

Research on microgrid technologies started relatively late in China. Compared with the huge research teams composed of research institutions, manufacturers and power companies in developed countries and regions such as Europe, the United States, and Japan, there is still a big gap in research strength and research results in China. With the continuous advancement and deepening of reform of the power system, however, China’s policies regulating the construction of microgrids have been continuously improving, which has strongly promoted the construction and development of microgrids.[11]

2.4 Existing Mini- and Microgrid Projects in China

In China, the microgrid projects that have been completed can be divided into island microgrids, remote areas microgrids, and urban area microgrids based on their geographic locations. Of these, urban area microgrids can be further divided into industrial microgrids, commercial enterprise and eco-city microgrids, civil microgrids and campus microgrids according to their uses.

(1) Island Microgrids

.The construction of domestic island microgrids is concentrated in the southeast coastal area. The main function of the microgrids are to solve the problem of electricity consumption and desalination of seawater for resident islanders and military garrisons situated on the islands. The main forms of generation for these island microgrids are wind, solar and diesel. Most of these systems are off-grid microgrids, which address the shortcomings related to the difficulty and high cost of laying and maintaining submarine transmission cables. A listing of examples of typical island microgrids in China is shown in Figure 6.

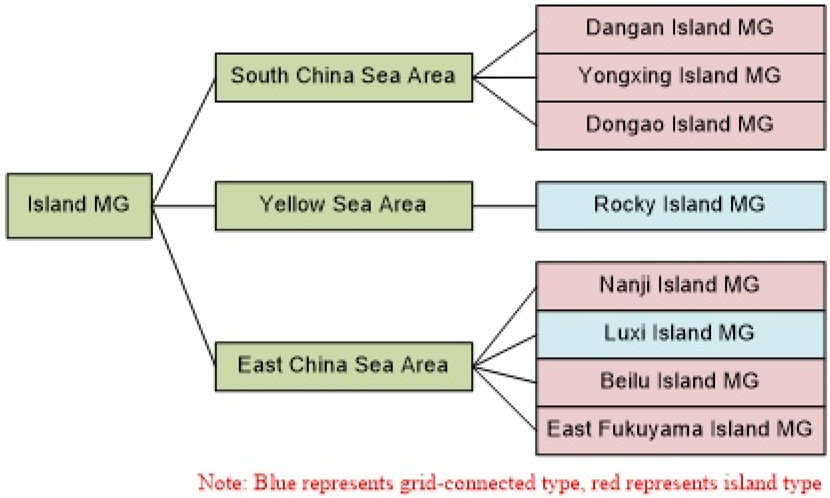

Figure 6: Typical Island Microgrids in China

(2) Remote-area Microgrids

These microgrid systems feature remote geographical locations and thus high costs of grid extension. These local areas have long been plagued by lack of electricity and unstable supply voltage when electricity was available, which has seriously affected the lives and productivity of the local residents. It is therefore imperative to develop microgrids in remote areas. Existing micro grids in remote areas are mainly located in high altitude areas such as Tibet, Qinghai, Inner Mongolia and Xinjiang. Microgrids in these areas are mainly independent, with solar energy and wind energy as the main energy resources used. Among these resources, solar energy is the most widely distributed and most used. The main microgrid projects in remote areas of China are shown in Figure 7.

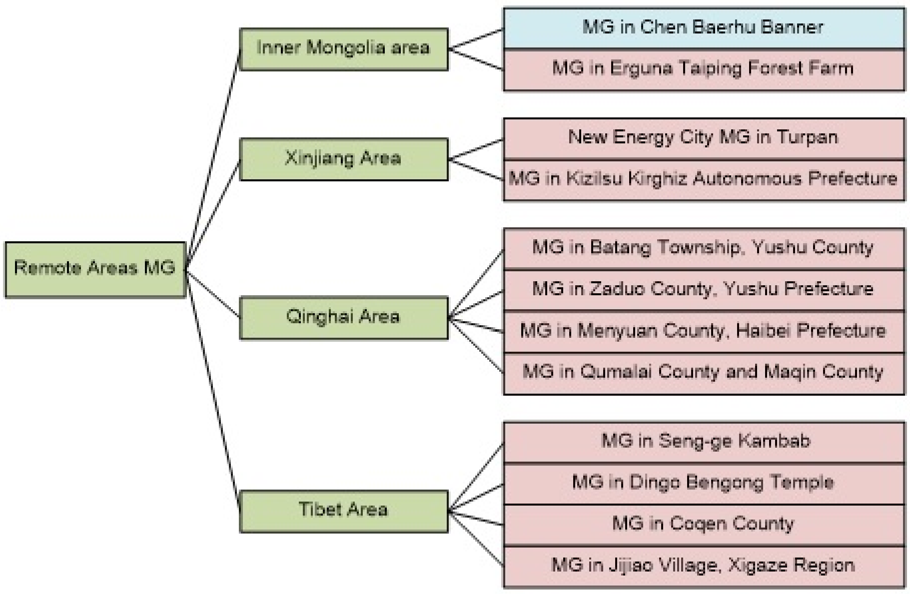

Figure 7: Typical Remote-area Microgrids in China

(3) Industrial Microgrids

Industrial power consumption is huge in China, with both high costs and high reliability requirements. As a local power grid, industrial microgrids cooperate with large power grids to provide reliable electricity for industries, which reduces electricity costs and industrial greenhouse gas and other air pollutant emissions and improves air quality. The construction of industrial microgrids is expected to be part of the development direction for smart cities in the future. Currently, there are not many pilot projects for industrial microgrids established in China, and the main projects that are currently active are shown in Table 2.

Table 2: Industrial MG in China

Application	Project	Type
Industrial MG	Jiangsu dafeng desalination seawater MG	Island
	Jiangsu dafeng wind power industrial park MG	Grid-connected
	MG in Yanqing, Beijing	
	Jindong MG	
	Baoding Tianwei MG	
	Beijing Huatai MG	
	Coba Factory MG	

(4) Commercial Enterprise and Eco-city Microgrids

Commercial enterprise microgrids are mainly used in commercial locations such as hotels, shopping malls, and entertainment venues. Table 3 shows the current status of commercial enterprise and eco-city microgrid construction in China. Most of the microgrids are distributed in cities, with these mainly grid-connected microgrids helping to solve the problems of high electricity prices and the need for meeting business-specific electricity demand for commercial enterprises and eco-cities, as well as to improve air quality and energy efficiency.

Table 3: Commercial Enterprise and Eco-city MG in China

Application	Project	Type
Commercial MG	MG in Shanghai Disney	Grid-connected
	MG in Beijing Zuoanmen	
	MG in Xi'an expo park	
MG in Ecological industry park	MG in Xinao Energy Ecological City	
	Sino-Singapore Eco-City Microgrid	
Enterprise MG	Wind-Light-Storage MG in ZhangBei	
	Cold-Electric Cogeneration MG in Foshan	
	MG in Huaneng New Energy Research Institute	
	MG in Changzhou Tianhe	
	MG in Hangzhou East Software Park	
	MG in Zhejiang Electric Power Research Institute	

(5) Civil Microgrids

Civil microgrids are mainly used in urban residential areas, and typically to date have been in the form of pilot projects, mostly serving households. These microgrids incorporate local renewable energy and combine clean energy generation with the concept of smart power consumption to improve the quality of power consumption, provide the individual power requirements of residents, and accumulate experience for the construction of civil microgrids more broadly in China in the future. The main civil microgrid projects currently operating are shown in Table 4.

Table 4: Civil MG in China

Application	Project	Type
Civil MG	Jibei paddock MG	Grid-connected
	Beijing Huazhongyuan Villa MG	
	Shanghai Chongming MG	
	Shaanxi Geopower Fuping Smart Community MG	

(6) Campus Microgrids

The campus microgrid is mainly used for university and other campuses and to provide power for laboratory scientific research. Campus microgrids' distributed power, energy storage, and load types are rich and diverse. The models and control methods used in these microgrids are relatively advanced, and flexible in structure, but small in scale. The main microgrid projects in China to date are shown in Table 5.

Table 5: Campus MG in China

Application	Project	Type
Campus MG	Xiamen University MG	Island
	Henan Finance College MG	Grid-connected
	Tianjin University MG	
	Zhejiang University MG	
	Hefei University of Technology MG	
	Beijing University of Civil Engineering and Architecture MG	
	Zhejiang University of Technology MG	
	Hangzhou Dianzi University MG	

3 Examples of Microgrid Development in China

3.1 Case Study #1

Project background

Dongao Island is located in the South China Sea about 17 km offshore and is under the jurisdiction of Zhuhai City. The island covers an area of about 4.663 square kilometers and has 400 residents. The island has a pleasant climate, is 82% covered by forests, and boasts an annual average solar resource of 5091.8 MJ/m^2. Before 2009, the entire island was completely reliant on diesel for power generation. This single fossil energy structure had the drawbacks of poor power quality, high electricity bills, frequent power outages, and serious pollution problems. In recent years, as the fuel consumption of the diesel power generation system increased year by year due to increasing loads, the diesel system was no longer able to meet the daily electricity needs of the residents on the island, and it became inevitable that the energy structure of the island would need to be transformed.

Project structure

The Dongao Island megawatt-level independent smart microgrid project was China's first megawatt-level microgrid system with complementary wind, solar, diesel, and energy storage, and was also China's first commercial-run island smart microgrid system. The project was constructed in two phases. In 2009, the project received a first batch of subsidies from the Ministry of Housing and Urban-Rural Development under the "Sunshine Roof Plan", and the installation of the first phase of nearly 400 kW was completed. Since then, without affecting the island's power supply, the project was expanded while continuing to operate. The entire project was completed in 2010. The integrated system structure of the microgrid is shown in Figure 8.

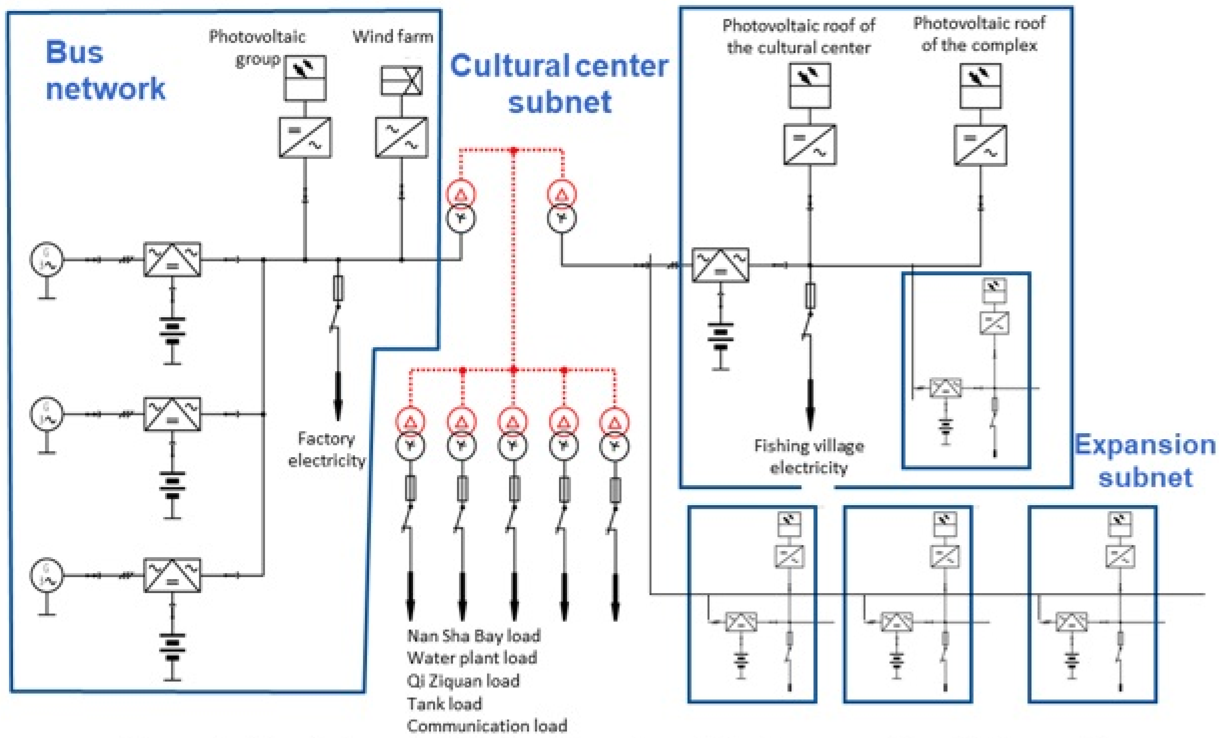

Figure 8: The Integrated System Structure of the Dongao Island Microgrid

Project effect

An analysis of power generation data from Dongao Island as of 2011, when the new microgrid system was in place, shows that there were three important effects of the implementation of the system:

(1) Increase in the proportion of renewable energy use and reduction of the use of fossil energy

Based on the analysis of power generation data for the full year of 2011, the maximum renewable energy utilization reached more than 90% in winter, more than 50% in summer, and 71.4% on average throughout the year, achieving a high percentage of the island/s renewable energy utilization goals. . The utilization rate of fossil energy for electricity generation dropped from 100% to 27.97%.

(2) Improvement in diesel engine power generation efficiency and reduction in power generation costs

Through the use of prediction, targeted deployment, and enhanced controls, the use of diesel engines for generation on Dongao has become much more planned and regular, and the power generation curve is smoother, thereby improving the power generation efficiency of the diesel units.

Through statistical analysis and comparison, the fuel consumption per kilowatt-hour of diesel generators in the microgrid system has been found to have been reduced from 317 L (liters) to 220 L, and power generation efficiency has increased by 30%. The average power generation cost of the diesel power plants has dropped from 4 yuan/kWh to 1.9 yuan/kWh.

(3) Improvement of the intelligence of the management system and reduction of equipment failure rates

Dongao's energy management system has been updated with equipment that can control the starts and stops of the diesel power generation system through a process of signal switching. An intelligent control box is attached to the photovoltaic array to monitor and control its power generation operation. The energy storage system prevents the batteries from overcharging or over-discharging by controlling the number of charge and discharge times and the depth of discharge in the whole process. The use of forecasting techniques to estimate the availability of solar energy and the electrical load on the island system makes it possible to analyze energy supply and demand trends more accurately, which is conducive to smooth operation of energy storage, dispatch and control. Through the estimation of the power generation side and the power user side, it can be determined whether the next command to the system should be to discharge or charge the battery, use diesel power generation, or use renewable energy power generation. All of the devices in the microgrid are monitored for safety, including systems for lightning protection, fire protection, overheating protection, theft protection, and others and automatic alarms are set to alert operators when abnormalities occur.[12]

3.2 Case Study #2

Project background

The Sino-Singapore Tianjin Eco-City is located in the Tianjin Binhai New Area, an important strategic area for national development. The area is located 45 kilometers away from Central City of Tianjin and 150 kilometers from Beijing. The Eco-city has a total area of approximately 31.23 square kilometers and planned population of 350,000. The Sino-Singapore Tianjin Eco-City offers convenient transportation and good energy supply guarantee conditions. It is an important living area serving the Binhai New Area. The smart grid of the Eco-City covers an area of 31 square kilometers and is currently the largest and most comprehensive smart grid demonstration area in the world. The project involves 6 major topical areas: power generation, transmission, transformation, power distribution, power consumption, and dispatch, and also included 12 sub-projects such as smart substations, power distribution automation, and a smart electricity sales hall.

Project structure

As a part of the Sino-Singapore Tianjin Eco-City project, two microgrids, an animation park and a smart power supply business hall have been built. The specific project structure of each microgrid is as follows.

(1) Smart power supply business hall microgrid

On September 5, 2011, the Sino-Singapore Tianjin Eco-City Smart Grid Comprehensive Demonstration Project and its associated microgrid system completed all commissioning. The Sino-Singapore Eco-City microgrid system is a low-voltage AC smart microgrid, consisting of 5 combinations of 30 kW photovoltaic arrays on the roof of the smart business hall , 6 1 kW wind turbines, 15 kW×4h (hour) lithium ion batteries as energy storage facilities, energy conversion devices, 10 kW of lighting devices in the business hall, a 5 kW charging pile load, and monitoring and protection devices. The microgrid is an autonomous system that can realize self-control, protection and management. It can run in conjunction with the external power grid or in isolation mode. Under daily conditions, the electricity used by the business hall is provided by wind power generation, photovoltaic power generation and the main grid. When main grid power is not available, the energy storage device enters discharge mode and supplies power to the business hall together with power from photovoltaic generation, wind power generation, and other devices. When the main grid is restored, the energy storage device will enter its charging mode, and the power supply of the business hall will return to normal. This type of intelligent network will greatly improve the reliability of power supply and avoid power outages.

(2) Animation Park microgrid

Eco-City Animation Park, covering an area of 240,000 square meters, became a focus of attention in 2016 when it entered official operation as the country's first megawatt-scale multi-micro grid project. The Eco-City Animation Park includes 1.489 MW of combined cooling, heating and power, nearly 917.5 kWp (peak kilowatts) of photovoltaics, and 400 kWh of energy storage. Two microgrid systems will be built to form a multi-microgrid in the park, realizing optimized operation of multiple energy sources such as wind, light, energy from storage, cooling networks, heating networks, and electricity generation, and forming an energy internet with coordinated, complementary, open and shared energy sources. By being equipped with public energy storage, this multi-microgrid reduces generation capacity requirements and investment needs. The system has a microgrid energy management system that can detect real-time peak and valley electricity prices in the animation park. Taking advantage of peak and valley pricing, the system uses stores electricity during peak hours on workdays when prices are higher, and stores electricity during valley hours on rest days (such as weekends) when costs are lower. The Animation Park Energy Station also provides electricity, cooling, and heat for the park through the comprehensive utilization of photovoltaic, gas, ground-source heat pumps, water storage, and other equipment. The use of integrated energy supply approaches can improve overall energy efficiency and reduce carbon emissions and other pollutant emissions. A diagram of the microgrid serving the animation park is shown in Figure 9.

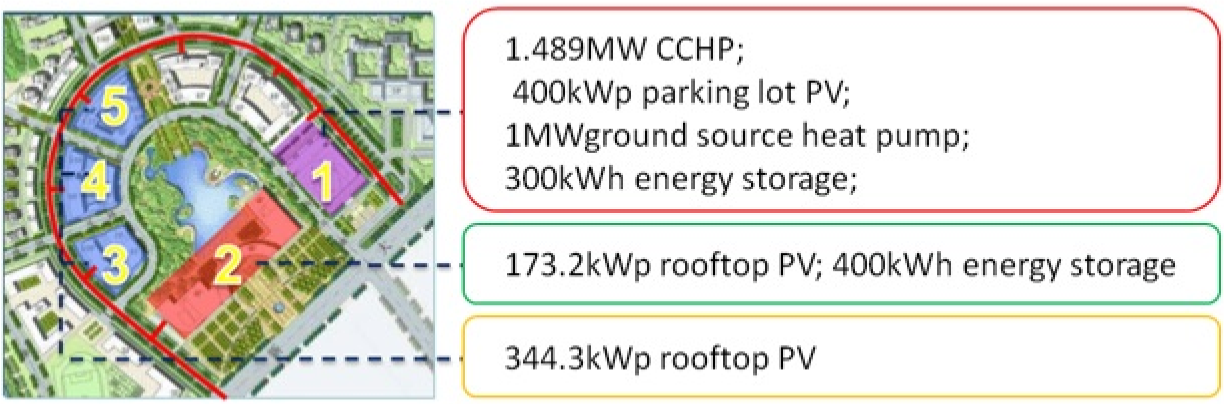

Figure 9: Diagram of the Microgrid Serving the Eco-City Animation Park

Project effect

Operational data from the Sino-Singapore Tianjin Smart Microgrid show three main aspects of project effects, as follows:

(1) Improvement in power supply reliability

Through the construction of multiple microgrids and the use of multi-point photovoltaic grid-connected construction, the Sino-Singapore Tianjin Eco-City Demonstration Project has greatly increased the proportion of new energy power generation used in the area, reduced power loss, eased the pressure on centralized power supplies, improved the situation of insufficient power supply, and provided energy security for the sustainable development of the regional economy. Through the microgrid, when the external power supplies are interrupted, supplies are switched to the stored energy generation state in a short time, improving the continuity and reliability of power supply. After the implementation of power distribution automation, the reliability of the Eco-City's power supply has been 99.999%, and the voltage qualification rate (the fraction of the time that system voltage remains within target levels) has increased to 100%. If converted to a metric of average annual power outage time, these changes mean a reduction from the original 20.7 minutes per year to 5.26 minutes per year.

(2) Improve the level of intelligence

The Sino-Singapore Tianjin Eco-City Demonstration Project can realize real-time remote control of smart home appliances, understand their electricity consumption, and rationally arrange the timing of the use of electrical appliances to realize "smart electricity usage". By 2015, the number of smart meters in the Eco-City reached 24,536 households, achieving full coverage of the project area. In addition, through equipment installed as part of the online monitoring system, self-perception of equipment status and self-diagnosis of microgrid network faults can be achieved, and the data needed for production management, monitoring equipment selection, and smart grid decision-making can be provided. On the power consumption side, the park has also built smart homes and installed automatic demand response equipment, while introducing technologies such as big data analysis and mobile internet facilities to build a comprehensive energy information service platform.

(3) Increase the proportion of renewable energy

The regulation of energy storage in the microgrid reduces the impact of photovoltaic instability on the grid and promotes the larger-scale application of photovoltaics. Another sub-project of the Eco-City Smart Grid Innovation Demonstration Zone is a megawatt-level regional smart microgrid in the Eco-City Animation Park of the National 863 Project, which has achieved a distributed photovoltaic penetration rate of more than 15% and a photovoltaic local consumption rate of 100%. In addition, research has been carried out on the comprehensive coordinated control of multi-source energy systems including photovoltaic power, wind power, distributed energy storage, megawatt-scale microgrid systems, electric vehicles, flexible loads, and combined cooling, heating and power in the park. As the microgrid is fully deployed, it will allow the centralized and rationalized allocation and consumption of energy, improve energy efficiency, and operate the grid economically and efficiently.[13]

4 Integrating Microgrids with Sub-National and National Grids

4.1 Current/Recent Protocols for Integrating Microgrids with the Sub-National and National Central Grids

Microgrid integration has changed the structure and operation mode of the power system at the medium and low voltage level, which is contrary to the traditional principles familiar to grid operation companies and equipment suppliers related to microgrid integration. Existing power supply principles and protection principles have been challenged. It is therefore urgent to formulate corresponding standards for microgrids at the national or industry level.

At present, China's microgrid grid-connection standards include 8 national standards and 6 industry standards, as shown in Table 6 and Table 7. Research on and compilation of the system of microgrid

grid-connected standards covers design, commissioning, acceptance, grid-connected testing, and operational control. In addition, the National Standardization Technical Committee for Microgrid and Distributed Power Grid Connection (SAC/TC 564) was established to be responsible for the development of the systems of standards, standard formulation, standard revision, and standard publication and dissemination for microgrid and distributed power grid connections. Additional standardization work is being coordinated with that of counterpart agencies such as the International Electrotechnical Commission and Technical Committee on Electric Power Supply System (IEC/TC8).

Table 6: National Standards for Microgrid Connections to Power Systems in China

List	Standard code	Standard Title	Implementation Date	Status
1	GB/T 33589-2017	Technical requirements for connecting microgrids to power system	2017/12/1	Current
2	T/CEC 5006-2018	Design code for microgrid connections to power systems	2018/4/1	Compilation
3	GBT 51250-2017	Code for the commissioning and acceptance of microgrids interconnected with distribution networks	2018/4/1	Current
4	GB/T 34129-2017	Specification for tests of microgrids connected to distribution networks	2018/2/1	Current
5	GB/T 34930-2017	Operation and control specification for microgrids connected to distribution networks	2018/5/1	Current
6	GB/T 36270-2018	Technical specifications for monitoring and control system of microgrids	2018/1/1	Current
7	GB/T 36274-2018	Technical specification for energy management systems of microgrids	2019/1/1	Current
8	GB/T 51341-2018	Standards for microgrid projects design	2019/6/1	Current

Table 7: Industry Standards for Microgrid Connections to Power Systems in China

List	Standard code	Standard Title	Implementation Date	Status
1	-	Standard for the commissioning and acceptance of microgrid connections to power systems	-	Compilation
2	-	Functional specifications of operation and control specification for microgrids	-	Compilation
3	-	Specification of operation management for isolated microgrid	-	Compilation
4	-	Technical specifications for monitoring and control of isolated microgrid	-	Compilation
5	-	Guidelines for microgrid planning and design	-	Compilation
6	-	Operation and control technical conditions for microgrids	-	Compilation

4.2 Barriers to Integration of Microgrids with Central Grids

The traditional power grid is a unidirectional power flow from power source to load. The connection of microgrids changes this operating characteristic. Microgrid connection influences will affect the voltage, line power flow, power quality, relay protection and network reliability. The degree of influence in any given example is closely related to the location, capacity, and load characteristics of the microgrid.[14]

Influence of microgrid connections on the power flow distribution of the power grid

When the power generated by the distributed power source in the microgrid is greater than the power of all loads, the microgrid is equivalent to a power supply in the large power grid and transmits energy to the large power grid. In this case, the nearby distribution network is powered by both the large grid and the microgrid, which changes the steady-state power flow distribution of the original distribution network.

Impact of microgrid connection on the static voltage of the grid

The continuous change of the output power of wind turbines and photovoltaic cells in the microgrid will lead to real-time changes in the penetration rate of the microgrid and fluctuations in the grid voltage. In addition, the introduction of microgrids will introduce power harmonics and can also cause grid voltage fluctuations. The harmonic current injected into the power system at the grid connection point should therefore not exceed the limits shown in Table 8. The even harmonics in the same range should be less than 25% of the lower odd harmonic limit, and the total harmonic distortion rate should be less than 5%.

Table 8: Percentage of Maximum Harmonic Current

Harmonic order /h (Odd harmonics)	$h<11$	$11\le h<17$	$17\le h<23$	$23\le h<35$	$35\le h$
Percentage /%	4.0	2.0	1.5	0.6	0.3

Influence of microgrid connections on the network line loss

Network losses are closely related to the energy flow on a given line. When the microgrid is connected to the central grid, the transmission of electric energy to the distribution network will reduce the energy flow of the grid branch and help reduce the network line losses on that branch. When the penetration rate of the microgrid is large, however a large amount of power is injected into the large grid, which causes the energy flow of the branch to increase, thereby increasing network losses.

Impact of microgrid connection on the transient stability of the power grid

When a microgrid is connected to the central grid, the power that penetrates the power system changes the original power flow distribution, line transmission power and parameter inertia, which will have a series of effects on the stability of the power system. In order to reduce the transient process that exists for both the microgrid and the grid during the grid connection, the voltage, frequency, phase angle and phase sequence difference between the microgrid and the grid must meet the requirements shown in Table 9.

Table 9: Limits of Synchronization Parameters When the Microgrid is Connected to the Grid

Parameter	$\Delta U/\%$	Δf/HZ	$\Delta\delta/(°)$
Requirement	±10	±0.4	±15

Table 9: Limits of Synchronization Parameters When the Microgrid is Connected to the Grid

Parameter	$\Delta U/\%$	Δf/HZ	$\Delta\delta/(°)$
Requirement	±10	±0.4	±15

Influence of the microgrid connection on relay protection

The connection of the central grid to a microgrid may increase the fault current or reduce the fault current, which may cause the relay protection device to malfunction or refuse to operate. When the power grid fails instantaneously, the microgrid may change from grid-connected state to off-grid state, affecting the reclosing of relay protection.

This potential impact makes it difficult for microgrids to connect to existing power grids on a large scale. To a certain extent, the relay protection impact hinders the development of microgrids, which makes the topic of relay protection an important research direction for China's microgrid studies in the future.

4.3 Policies Related to Microgrid Development in China

Research into microgrid technologies started relatively late in China. Generally speaking, compared with the huge research teams composed of research institutions, manufacturers and power companies in developed countries and regions such as Europe, the United States, and Japan, China still shows a large gap in research strength and research results. In recent years, with the continuous advancement of deepening the reform of the power system, China's policies for the construction of microgrids have been continuously improved, which has promoted the construction and development of microgrids.[15]

Before 2015, the state issued many individual incentive policies for renewable energy, but there were no policies for specific promotion of overall microgrid systems. The areas of microgrid access, planning and design, construction and operation, and equipment manufacturing all lacked corresponding national-level technical standards and management norms, resulting in slower development of microgrids.

Since 2015, the State has begun to attach importance to the development of microgrids, and has successively issued a large number of related policies on the construction and management of microgrids, as shown in Table 10. Based on this series of policies related to microgrids, it can be seen that the microgrid policy system in China is gradually becoming sound and comprehensive. From the initial encouragement and promotion of the development of microgrids, microgrid policy has evolved towards demonstrating the practice of comprehensive energy storage technology applications, creating conditions for the further promotion of microgrid construction.

Table 10: Policies Related to China's Microgrid Development in 2015-2019

time	institutions	Policy name
2015.03	Central Committee of the Communist Party of China, State Council	*Several Opinions on Further Deepening the Reform of the Power System*
2015.07	National Energy Administration	*Guiding Opinions on Promoting the Construction of New Energy Microgrid Demonstration Projects*
2016.12	State Council	*Guiding Opinions on Promoting the Development of "Internet +" Smart Energy*
2017.02	National Energy Administration	*Microgrid Management Measures*
2017.05	National Energy Administration	*Notice on the List of New Energy Microgrid Demonstration Projects*
2017.07	National Energy Administration	*Implementation Measures for Promoting the Construction of Grid-connected Microgrids*
2018.08	National Development and Reform Commission	*Measures for Power Supply Supervision*

In the future, the State's policy support for microgrids will continue to increase, and market conditions for microgrid development and operation will become increasingly mature. The future development prospects for microgrids are promising, but require continued efforts toward standardization. The need for standardization in turn suggests very high requirements for the collection of follow-up information and statistics on microgrids, as well as operational supervision by relevant government and energy authorities, including development and collection of assessment indicators such as the local consumption of renewable energy within the microgrid, comprehensive energy utilization efficiencies, and the market behavior of microgrid entities. These all require the supervision of the whole microgrid deployment and operational process, necessitating a long-term and systematic approach to standardization, regulation, and data collection.

5 Evolving and New Microgrid Technologies in China

After years of development in China, microgrid technologies have achieved remarkable results, but there are still a lot of smart device issues that need to be addressed throughout the entire microgrid system. At the same time, microgrid technologies faces new challenges under the background of the new era of electricity sector development. It is therefore necessary to improve on original technologies and develop new technologies to further the development of microgrids in China. The key technologies for the development of China's microgrids that require further special attention are control technology, intelligent protection technology, power electronics technology, renewable energy technology and energy storage technology.[16]

(1) Control technology

The State Grid Fujian Electric Power Research Institute has proposed a microgrid structure and control method based on solid-state switches, droop control, source-load balance and DC convergence. The solid-state switch is used to quickly isolate faults in the distribution network, the droop control strategy is used to realize the switching of the on-grid and off-grid operational modes when power flow is uninterrupted, and the source-load balance is used to realize the balance of the source-load power of the microgrid in on-grid and off-grid operations. Using this structure, in the case of loss of power supply from the distribution network the microgrid can smoothly switch to off-grid operation continuously, effectively ensuring the reliability of power supply for the loads served by the microgrid.

(2) Intelligent protection technology

The Shandong Electric Power Research Institute has proposed an intelligent fault diagnosis method suitable for microgrids. This method provides functions for the diagnosis of both external faults of microgrids and internal short circuit faults, which provides the basis for the operational control and related protection of microgrids.

(3) Energy storage technology

The China Energy Construction Jiangsu Energy Technology Co., Ltd. has proposed a microgrid energy storage optimization dispatch method that includes consideration of the intelligent microgrid structure of AC/DC converters and the types of consumption of DC/AC hybrid power. The method considers both AC load and DC load, and optimizes the conversion state of the AC-DC converter and the charging and discharging state of energy storage batteries, thereby achieving the saving of electricity during battery energy storage and discharge. The method is suitable for different types of microgrid users.

(4) Power electronics technology

The Beijing Tiancheng Tongchuang Electric Co. Ltd. has proposed a microgrid control device that has a tailorable function such that the number and types of connected devices can be flexibly configured according to the needs of the microgrid project. This increases the adaptability of the control equipment to the needs of different projects, which facilitates subsequent on-site maintenance and on-site secondary upgrade and expansion of microgrids.

(5) Renewable energy technology

Southeast University has proposed a multi-scale wind and solar complementary island microgrid energy control method based on a MAS (multi-agent systems) approach. The control method adopts distributed energy management technologies, which can reduce the instability of the output power of the wave power generation system to produce a relatively stable total output. As an element to deploying microgrid systems to ensure power supply, the control method greatly reduces the number of batteries required, reduces system investment costs, and improves the reliability of island microgrids.

6 Conclusions

6.1 Brief Summary of the Current Status of Microgrid in China

From the perspective of the national energy transition in China, social industry development and power grid enterprise development, microgrid technology will see significant development opportunities in the coming years. In the future, smart grid deployment will cause a huge demand for microgrid technologies adapted to the changing national energy structure, changes in the energy industry, and the social development that those changes support. As an important part of the smart grid of the future, microgrids will play an important role in the future power grid by taking advantage of its strengths such as accommodation of diversification of energy forms, flexibility of grid connection interfaces, customization of power quality, and bi-directional energy information flow.[17]

Based on the microgrid project analysis, ongoing technological innovation, and policy development described in this paper, it is not difficult to see that China's micro-grid policy system is gradually becoming increasingly sound, comprehensive, and effective. Starting with initial government encouragement and promotion of the development of microgrids, policies have evolved to include demonstration and practice of comprehensive energy storage technology applications. Policies related to microgrids have been promulgated continuously, lists of related demonstration projects for microgrids application have been announced regularly, and pilot projects have been established one after the other, laying the foundation for the full promotion of microgrids in China. Under current policy conditions, with the continuous advancement and deepening of reform of the nation's power system, China's policies for the construction of microgrids have been continuously improved, which strongly supports the construction and development of microgrids.[18]

6.2 Brief Summary of Current and Future Policies Related to Microgrids in China

With the progress of microgrid technology and the promulgation of a series of national policy documents to promote the development of new energy microgrids, China's microgrid industry is entering a period of rapid growth. Some of the recent and current positive impacts of microgrids on the energy situation in China include the following"

(1) Optimization of the energy structure and promotion of energy conservation and environmental protection. Making full use of renewable energy for power generation is of great significance to China's ongoing adjustment of its energy structure, improvement of energy efficiency, reduction of environmental pollution, development of the western region, solving the problems of rural energy use and provision of power in remote areas, and construction that avoids ecologically impacts or improves the local ecology.[19]

(2) Improvement of power supply reliability and improvement of power quality. As the fragility of large power grids is becoming increasingly prominent, important loads with close geographical locations should be formed into microgrids, and appropriate circuit structures and controls should be designed so as to provide high-quality and reliable power for these loads, and to attract more high and new technology to China.

(3) Reduction of power outage losses and realization of economic operation. Flexible parallel operation modes between microgrids and the large grid can allow microgrids to play the roles of peak shaving and valley filling in the daily and weekly demand curves so that the power generation equipment over the entire grid can be fully utilized. Not only can this function of microgrids save unnecessary costs while improving overall reliability, it can also reduce the economic losses incurred when important loads suffer power outages, as well as improving system economy.[20]

6.3 Needs for Policy and Technical Development to Promote Wider Dissemination of Micro-grid in China

Although the development of microgrid technology in China has achieved some remarkable results, there are many bottlenecks in the comprehensive application and operation and control mode of microgrids involving advanced power electronics, computer control, communications and other technologies. These needs are mainly reflected in the following issues. 1) Microgrid operation is relatively difficult, as the energy balance in many microgrid is too dependent on the large grid, and thus microgrid economy and reliability cannot be guaranteed. 2) Key microgrid technologies of such as energy storage are in urgent need of improvement, and the commercial application of energy storage is facing cost issues. 3) The high investment cost required for the construction of microgrid systems restricts their development. 4) Microgrids lack effective control methods.

These problems have limited the development of microgrids in China to a certain extent. But as an important part of the smart grid, microgrids are an important route to improvement of the penetration and efficiency of renewables in power generation. Microgrids provide an effective way to save energy, reduce emissions, and improve power supply reliability, and can also be a powerful supplement to the large power grid. Therefore, the development of microgrids and the construction of UHV (ultra-high voltage) grids are both of strategic significance for reducing system vulnerability and improving grid survivability and disaster resistance, particularly under a changing climate. With the continuous promulgation of new policies, continuous technological improvement, continuous declines in construction costs, and the improvement of standards for microgrid deployment and operation, the construction of microgrids will show explosive growth, and the prospects for microgrids are bright in China.

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