博 士 論 文

OPTIMAL ANALYSIS OF ENERGY-SAVING TECHNOLOGY AND ELECTRICITY MARKET FOR DEMAND SIDE MANAGEMENT

デマンドサイドマネジメントの省エネルギー技術と電力
市場の最適分析に関する研究

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Optimal Analysis of Energy-saving Technology and Electricity Market for Demand Side Management

ABSTRACT

Demand side management (DSM) is an important means to regulate user load and relieve power grid pressure. Demand side management (DSM) has been popularized earlier, but the implementation progress is different in different countries. At the same time, the rapid development of renewable energy and power market has brought new changes to DSM. This study took Japan as an example to study the influence and promotion effect of policy, electricity price and demand side characteristics on energy saving technology, which hope to identify the DSM work in Japan and verify the actual effect. Combined with the promotion process of Japan's power market, theoretical reference for the future development of DSM could be provided. The results showed that the promotion and performance improvement of microgrid and air conditioning system are most suitable for the development of DSM. At the same time, the liberalization of electricity market is helpful to the promotion of demand side technology.

In chapter 1, RESEARCH BACKGROUND AND PURPOSE OF THE STUDY. The development background and specific implementation forms of demand side management were systematized and summarized. Distributed energy and power market liberalization, two key development directions of technology side and economic side, were discussed in detail. Finally, Japan's relevant policies were elaborated, and the research objectives and specific contents are put forward.

In chapter 2, DEVELOPMENT PROCESS AND RESEARCH STATUS OF DEMAND SIDE MANAGEMENT (DSM). The typical development process of demand side management was sorted out. Then, the related research on the technology and economic side of DSM were summarized. Finally, the application of computer and Internet technologies such as machine learning and blockchain in DSM was described.

In chapter 3, TECHNICAL SIDE EQUIPMENT MODELING AND ECONOMIC SIDE THEORETICAL DERIVATION. The research method was proposed, and the demand side load analysis and technical side equipment characteristics analysis were carried out. At the same time, the economic side means of demand side management was studied theoretically.

In chapter 4, THE PROMOTION ANALYSIS OF POLICIES ON THE TECHNICAL SIDE OF DSM. The research studied the effect of Japan's "top runner"

policy on equipment energy efficiency improvement and analyzed the rebound effect of carbon emissions in the whole life cycle. The importance of energy efficiency improvement of demand side equipment was analyzed by factor decomposition model, and the implementation effect of the policy was identified by moving window and correlation analysis. Finally, the rebound effect of energy efficiency improvement of air conditioning, passenger car and lighting was analyzed. The results showed that the policy has the best promotion effect on air conditioning system.

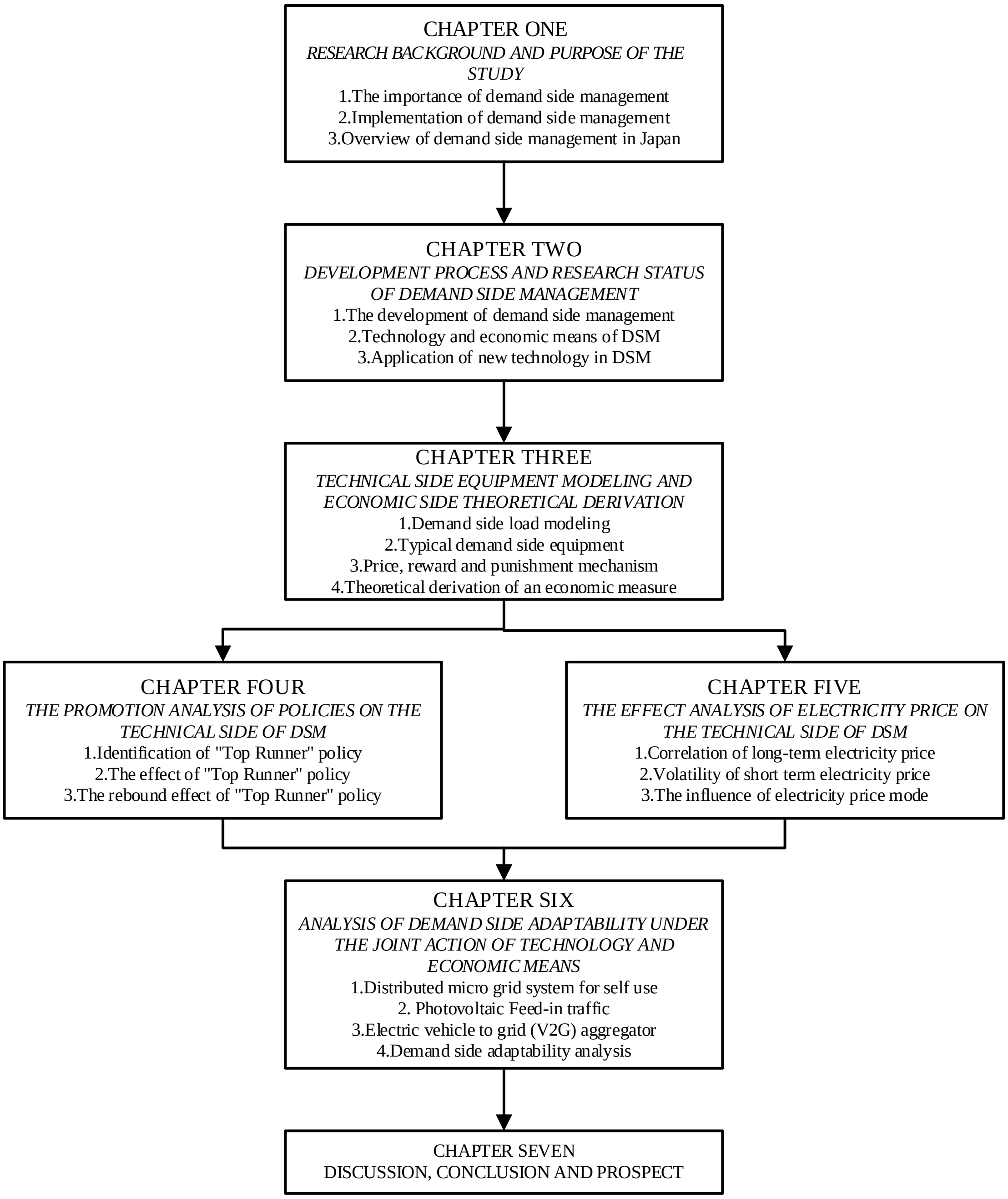
In chapter 5, THE EFFECT ANALYSIS OF ELECTRICITY PRICE ON THE TECHNICAL SIDE OF DSM. The correlation analysis of electricity price, the short-term forecast and the influence of different electricity price modes on technical side means were analyzed. At the same time, hybrid electricity price and widening the gap between peak and valley electricity prices are conducive to the promotion of LED lighting and energy storage battery respectively.

In chapter 6, ANALYSIS OF DEMAND SIDE ADAPTABILITY UNDER THE JOINT ACTION OF TECHNOLOGY AND ECONOMIC MEANS. The adaptability of different types of buildings under different demand side liberalization degrees was compared. Firstly, the typical demand side load was obtained by reducing the dimension of the target building. Then, three kinds of demand side liberalization degrees, namely, self-use, photovoltaic grid price and free trade, were set to study the adaptability of different typical demand side loads to different degrees of liberalization. The results showed that in the case of low demand side liberalization, users with gentle load change have advantages. In the case of high degree of liberalization, shopping malls with obvious load difference but strong regularity are more suitable to participate in power trading as load aggregators.

In chapter 7, DISCUSSION, CONCLUSION AND PROSPECT. The discussion and conclusions of whole thesis is deduced and the future work of DSM has been discussed.

俞 丹 博士論文の構成

Optimal Analysis of Energy-saving Technology and Electricity Market for Demand Side Management



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Chapter 1

RESEARCH BACKGROUND AND PURPOSE OF THE STUDY

CHAPTER ONE: RESEARCH BACKGROUND AND PURPOSE OF THE STUDY

1.1 Background

At present, the energy world is full of huge contradictions. There are a series of gaps between the status quo of energy system and the future development goals. On the one hand, it is the initiative of sustainable energy for all. On the other hand, there are still 850 million people without electricity in the world. The world needs to step up efforts to reduce greenhouse gas emissions, while energy related carbon emissions hit a record high in 2018. The world is full of expectations for renewable energy to promote the rapid transformation of energy, but the current energy system is still highly dependent on fossil energy. On the one hand, it is to seek sufficient and stable oil supply. On the other hand, the geopolitical situation continues to be tense and uncertain.

The two major challenges in the global energy transformation stage are the increasing demand for energy and the limitation of carbon emissions. According to International Energy Agency (IEA) statistics, the industry, transportation and residential sectors are the highest energy consumption areas. The three sections with the most CO2 emissions are electricity and heat producing, industry and transportation[1]. In the BP World Energy Outlook by British Petroleum (BP), the growth of energy demand will be largely offset by the decline in energy intensity in a gradual transformation scenario[2]. The improvement of energy efficiency can effectively reduce energy consumption and CO2 emissions. So many countries have introduced relevant policies aimed at improving energy efficiency [3; 4]]

The IEA found that COVID-19 caused global economic downturn, which led to a 3.8% drop in energy demand[5]. Overall, compared with the first quarter of 2019, global electricity demand decreased by 2.5% in the first quarter of 2020, and global carbon dioxide emissions decreased by more than 5%, as shown in Figure 1-1[6].

Of all energy sources, only renewables have grown. And it is expected that by 2020, renewable energy power generation will grow by nearly 5%. This shows the firm determination of the global energy transformation, and promoting the development of green economy has become a global consensus. Increasing the popularization of clean electricity is the key to realize decarbonization in the world today.

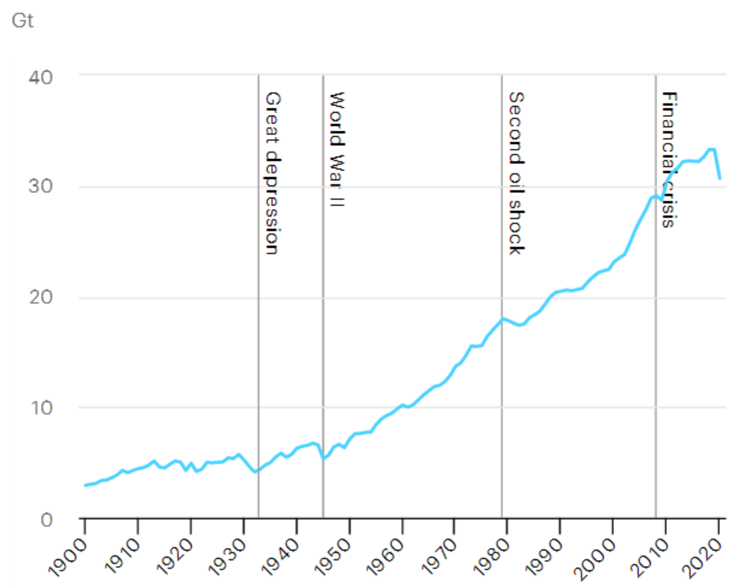

Figure. 1-1 Global energy-related CO_2 emissions, 1900-2020[6]

According to the IEA sustainable development scenario, by 2070, the share of electricity in the final energy demand will increase from the current 20% to nearly 50%.and the contribution to the cumulative carbon emission reduction will be nearly 1/5. The demand for electricity will increase by 30000 TWH by then[7]. This means that from now to 2070, the annual increase in electricity demand is equivalent to the sum of the current annual electricity demand in Mexico and the United Kingdom, which is bound to promote a wider range of clean power applications, including solar, wind and nuclear power. Technologies such as renewable energy and electric vehicles, which are in the early application stage, have a certain degree of flexibility in response to the epidemic, and will continue to accelerate development in the near future. Renewable energy electricity generation is expected to grow by 7% year on year in 2021, accounting for 30% of global electricity supply. In 2020, global auto sales will drop by 15% year-on-year, but electric vehicle sales will be flat[8].

In 2019, coal accounted for 38% of global electricity, 1% lower than in 2000. With the adoption of supercritical and ultra-supercritical technologies by power plants, the proportion of subcritical power plant in coal-fired power plant has decreased from 75% in 2000 to 40% in 2019, and coal-fired power emissions have gradually decreased. However, the reserves of fossil energy represented by coal and natural gas are limited, and emissions are inevitable when they are used. Therefore, in the future energy structure, it is bound to vigorously develop hydrogen, wind power, photovoltaic and other clean renewable energy, as shown in Figure 1-2[9]. Wind power, photovoltaic and other renewable energy power generation promote the further green transformation of energy system.

Among them, solar photovoltaic power generation will increase by about 25% in 2019, reaching more than 710 TWH.

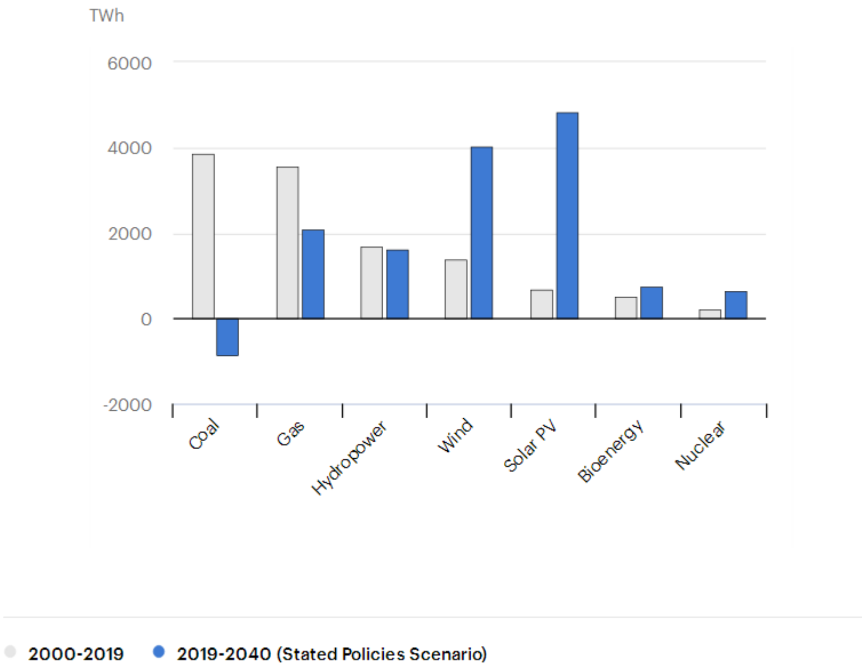

Figure 1-2 Change in global electricity generation by source in the Stated Policies Scenario, 2000-2040

The power sector will be one of the first industries to achieve decarbonization through the use of low-carbon technologies such as renewable energy, CCUs and nuclear energy. By 2070, global power generation will nearly triple, with about 70% of the growth to meet the growing electricity demand of the end sector, while 30% of the growth will be in the production of low-carbon fuels, especially hydrogen. As shown in Figure 1-3[10], in the sustainable development scenario, the power generation sector will be completely decarbonized by the 1950s, and the global construction and passenger vehicle sectors will reach zero emissions by 2070.

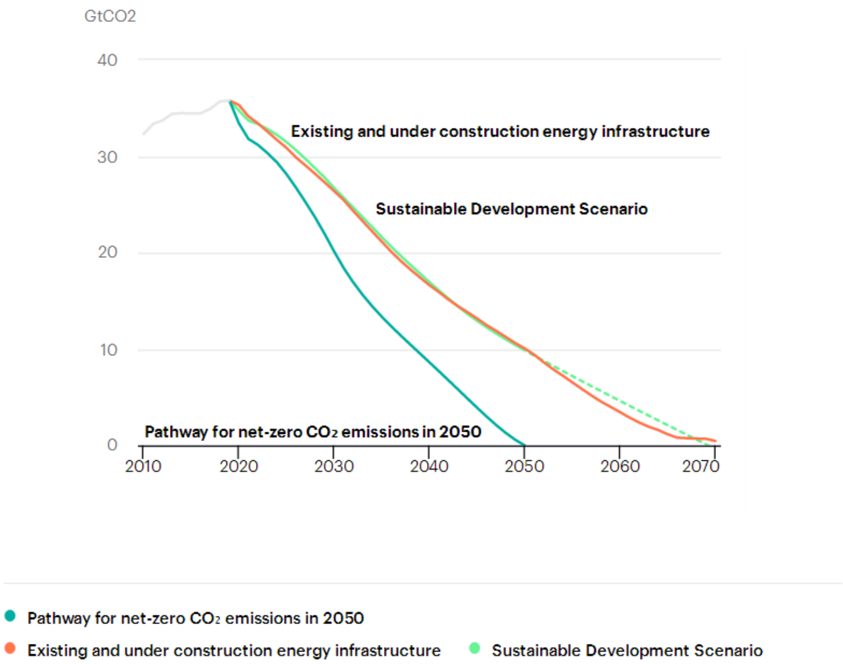

Figure. 1-3 Historical and projected CO2 emissions from energy infrastructure in use and power plants under construction operated in line with past practice, 2010-2070

Under the dual challenges of economic downturn and energy transformation, in the coming decades, the global energy structure will become more diversified, and the competition among various energy producers will become increasingly fierce. With the preference of consumers and governments for clean and low-carbon energy, renewable energy will penetrate into the energy system at an unprecedented speed in the future. The proportion of renewable energy in primary energy will rise from 5% in 2018 to 20% to 60% in 2050. Electricity system operators all over the world are trying to solve the volatility of renewable energy supply. At the same time, the coal electricity output is decreasing year by year, and the user demand is becoming more and more diversified. In the future, more emerging technologies such as energy storage system, natural gas peak shaving, customer side response and virtual power plant will be applied in power system. As shown in Figure 1-4 [11], In the situation of increasing electricity demand, the global electricity structure will also become more diversified. With the liberalization of electricity market competition, customers can choose their own electricity resources. The electricity market will need more integration to adapt to this more diversified supply.

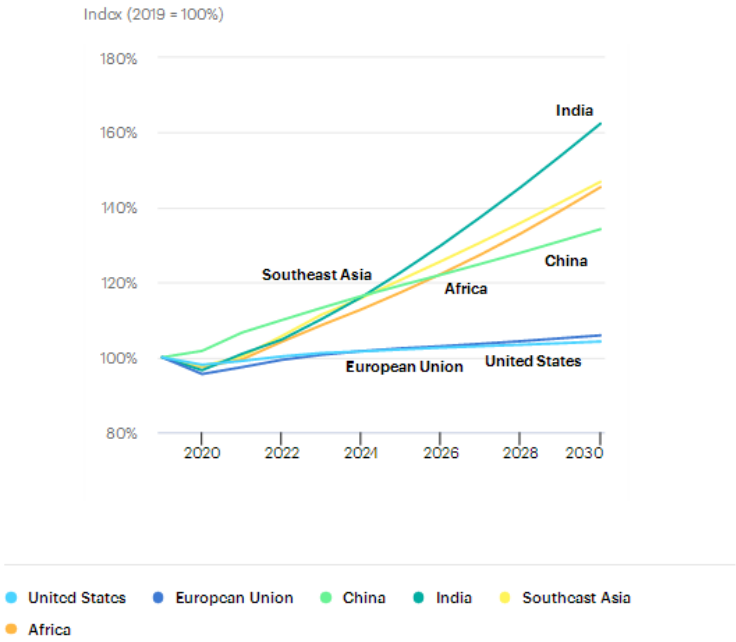

Figure. 1-4 Electricity demand outlook in selected regions/countries in the Stated Policies Scenario, 2019-2030

With the growth of per capita GDP and the popularity of electrification, the gap between the peak and the valley of power supply has been widening. According to the statistics of Shanghai power load management center of China, the highest power consumption load of Shanghai in 2016 was 3138MW in China, with the valley load of 8620MW, and the ratio of peak to valley was about 3.6 times. In 2017, the peak load of Tokyo was 5383MW in Japan, 1977MW in valley load, and the peak valley ratio was about 2.7 times.

Electricity grids could prove to be the weak link in the transformation of the power sector, with implications for the reliability and security of electricity supply. The projected requirement for new transmission and distribution lines worldwide in the STEPS is 80% greater over the next decade than the expansion seen over the last ten years. The importance of electricity networks rises even more in faster energy transitions.

In order to ensure the safety, stability and economic operation of the electricity grid, measures must be taken in the power generation side for peak load regulation. However, the peak shaving capacity of the grid is limited in unit life, low energy utilization and high investment cost. Therefore, the demand side peak shaving measures are particularly important. Demand side management(DSM) is a kind of electricity management activity. Among them, the electricity industry (Supplier) takes administrative, economic and technical measures to encourage users (demand side) to take various effective measures to change their electricity consumption behavior, and to improve power efficiency and optimize resource allocation by reducing energy consumption and power load[12].

Demand side response(DR) is a derivative of demand side management. It is proposed by the United States after the electricity market reform, aiming at how DSM can play a full role in the competitive market to maintain system reliability and improve market operation efficiency. In a broad sense, DR can be defined as the market participation behavior of consumers in the electricity market that respond to the market price signal or incentive mechanism and change the normal electricity consumption pattern. DR organization of the United States is relatively perfect, and the types of projects are rich. The market mechanism and operation rules of DR are managed and implemented by the states according to their own actual conditions. For example, California major operational load participation plan, demand reduction plan and other projects. New York state mainly uses interruptible load to participate in day ahead spot market or operational reserve market. New York state mainly uses interruptible load to participate in day ahead spot market or operational reserve market. Similar to the United States, European countries carry out DR according to their own schemes and rules, while the European Union pays more attention to the development and construction of key DR platforms and the formulation and revision of smart electricity standards.

DSM took the lead in the U.S. in the 1970s and made significant progress in the development of DSM in response to the global environmental crisis twice. Since the oil crisis, about 50% of developed countries have reduced energy consumption per unit GDP through various measures, including DSM. In developing countries, such as DSM in China in the past 30 years, has achieved remarkable results. From 2012 to 2016, 55.3 billion kwh of electricity and 12.68 million kw of electricity were saved, equivalent to 31 million tons of loose burning coal, 55.1 million tons of carbon dioxide and 17.53 million tons of sulfur dioxide, nitrogen oxides and dust pollutants. The maximum peak load can reach 16 million kilowatts through orderly electricity consumption transfer. Through the implementation of a series of comprehensive measures such as DR, the peak load has been reduced by more than 2.83 million KW from 2013 to 2015 [13].

1.2 Overview and development of DSM

1.2.1 Overview of technical means

DSM proposed mainly for energy efficiency management, load management, orderly power consumption in the early stage. The means of implementing DSM are mainly divided into administrative means, technical means and economic means. DSM mainly puts forward energy efficiency management, load management and orderly electricity consumption in the early stage. It is an important energy-saving way, aiming at reducing the load demand, reducing the installed capacity, transferring part of the peak load to the low period, and reducing the load peak valley difference. The means of implementing DSM can be divided into administrative means, technical means and economic means. At present, the classification of energy saving in DSM theoretical framework is shown in Figure 1-5.

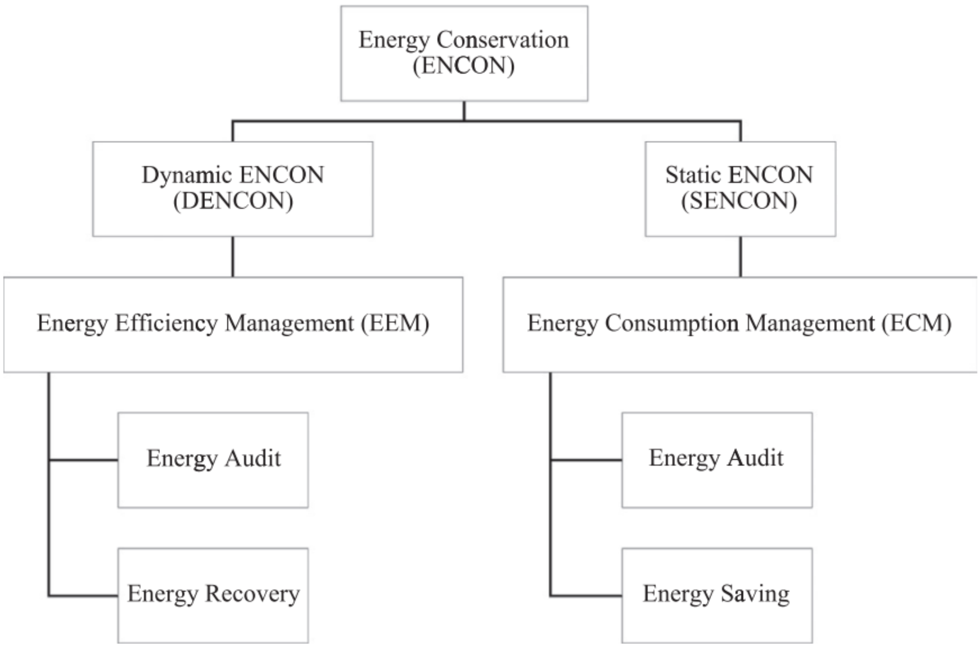

Figure 1-5 Classification of Energy Conservation in the proposed DSM theoretical framework[14].

Administrative means management means a kind of government regulation of management activities through laws, standards, policies and systems. Electricity consumption and market behavior promote energy conservation and emission reduction, restrain waste and protect the environment of the government's only administrative power[15]. Specifically, the government encourages all parties, such as power companies, to participate in the implementation of the administrative regulations formulated by the DSM program. Enterprises should be encouraged to adopt energy-saving products and technologies. The realization of administrative means is often achieved through the implementation of technical and economic means. Therefore, the core means of DSM are technical means and economic means.

Technical means refers to the use of advanced energy-saving technology and management technology and corresponding equipment to improve terminal power efficiency or change power consumption mode according to specific management objects, production process and living habits. The technical means adopted to change the mode of power consumption and improve the efficiency of terminal electricity consumption are different.

1. Changing the way users use electricity

1) Direct load control

Direct load control (DLC) is a method for system dispatchers to control terminal electricity consumption through load control device during peak load period. DLC is usually used in industrial power consumption control, and the priority control is based on the principle of minimum outage loss.

2) Time controller and demand limiter

The ideal control method for peak load shifting is to realize intermittent and cyclic load control by using automatic control devices such as time controller and demand limiter.

3) Low valley and seasonal electrical equipment

Adding low-valley power equipment, that is, the peak electricity grid in summer can appropriately increase the winter electricity equipment, and the winter peak electricity grid can appropriately increase the summer electricity equipment. In the period of low daily load, the electric boiler or heat storage device is put into use for electrical insulation, and electric heating or air conditioning can be used to fill the valley in the late winter night.

4) Energy storage device

Electric energy storage devices are put into use to fill the valley during the period of low daily load of electricity grid, such as electric heat accumulator, electric vehicle storage battery and various charging devices which can be arranged randomly.

5) Cold storage and heat storage device

The most effective way to shift peak load and fill valley is to use cold storage and heat storage technology. In the low load period of electricity grid, the energy is stored by cold storage and heat storage, and released for conversion and utilization in the peak load period, so as to achieve the purpose of peak load shifting and valley filling.

2. Improve terminal electricity efficiency

To improve the efficiency of terminal electricity consumption is achieved by changing the consumer behavior of users, using advanced energy-saving technology and efficient equipment. The fundamental purpose is to save electricity and reduce electricity consumption, including direct and indirect electricity saving. Direct electricity saving is to use scientific management methods and advanced technical means to save electricity; Indirect electricity saving depends on improving economic management, adopting adjustment and control measures to reduce electricity consumption.

1) Lighting uses compact fluorescent lamps to replace ordinary incandescent lamps,thin tube fluorescent lamp is used to replace common thick tube fluorescent lamp, sodium lamp is used to replace mercury lamp, high efficiency inductance ballast is used to replace ordinary inductance ballast, electronic ballast is used to replace common inductance ballast, high efficiency reflector cover is used to replace common reflector lamp cover. In addition, intelligent switches such as voice control, light control, time control and sense control and key switch control are adopted to realize lighting power saving operation.

2) The electric motor with high conductivity and magnetic conductivity is used to replace the ordinary motor, the motor matching with the production process is selected to improve the average load rate of operation, various speed control technologies are applied to realize the electric saving operation of the motor, the flow operation is realized, and the empty load rate of the motor is reduced.

3) Refrigeration and air-conditioning use lithium bromide absorption refrigeration to reduce electricity consumption, and use intelligently controlled high-efficiency air conditioners and heat pumps to replace heating and air-conditioning with resistance heating to save electricity. Through the establishment of consumer behavior to adapt to human physiological conditions to reduce electricity consumption.

4) order to reduce the line loss, the high-efficiency transformer with low copper core loss is used to reduce the frequency of electricity transformation. The distribution loss is reduced by implementing the electricity saving operation of transformer, reasonable distribution line layout and adopting reactive power local compensation.

5) Through the application of dry quenching, high temperature waste heat recovery power generation, industrial furnace high temperature waste heat recovery power generation, blast furnace top discharge pressure power generation, industrial boiler residual pressure power generation to recover residual heat, it can be used to improve energy utilization and increase end-user self-

sufficiency. Heat recovery and heat conduction equipment such as heat pump, heat pipe and high efficiency heat exchanger are used to reduce electricity consumption directly or indirectly.

6) Reasonable scheduling, through the implementation of specialized centralized production, improve the loading rate of furnace floor and reduce the electricity consumption per unit product. Continuous operation is carried out to reduce the loss of blowing in and shutdown and improve the electricity consumption efficiency of the equipment; fans, pumps and compressors operate economically.

7) Building energy conservation through the use of high thermal insulation wall materials and doors and windows structure, full use of natural light and heat.

8) Energy substitution is to replace solar energy and gas with electric energy, so as to make more economic and rational use of energy resources.

1.2.2 Overview of economic means

DR is specific technique of DSM. It can be divided into IBDR and PBDR, as shown in Figure.1-6.

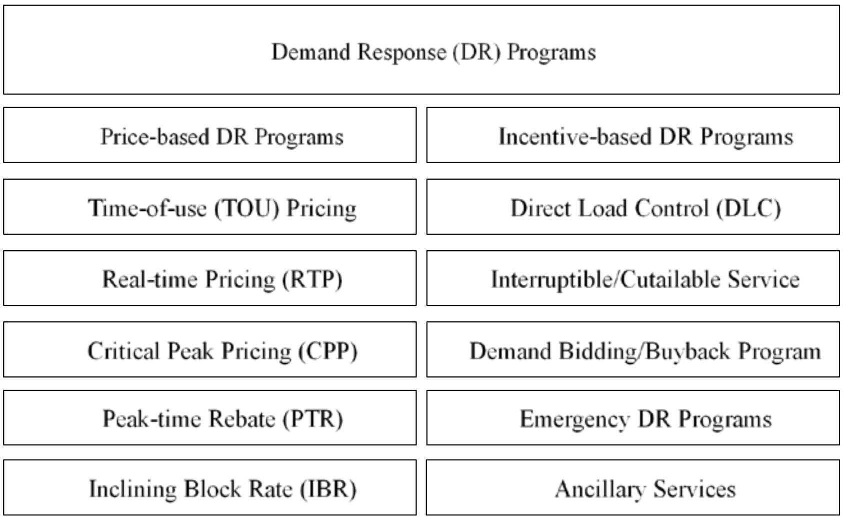

Figure 1-6 DR programs[16]

In a market economy, every commodity has a price that shows its value. Electricity is a special commodity and has its specific price. Electricity price is the monetary expression of the value of electricity commodity in the process of generation, supply and use exchange. According to the price chain of the whole process of power generation, supply and marketing, electricity price can be divided into two types: generation company's on grid price, power grid company's transmission and distribution price and terminal sales price.

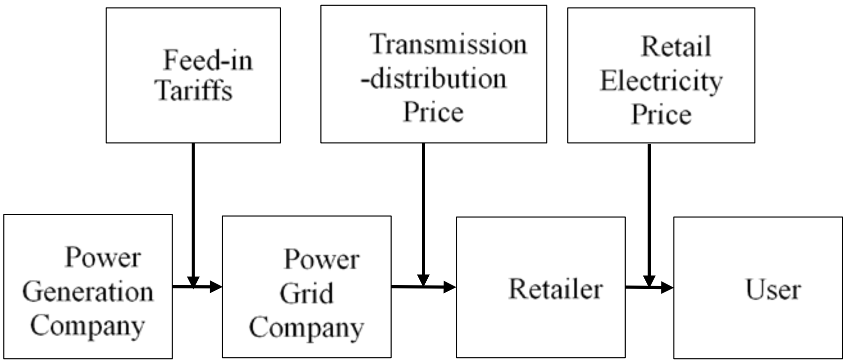

Figure 1-7 Power generation, transmission and distribution, supply and consumption system diagram

As shown in Figure 1-7, the process of power supply also constitutes the formation process of electricity price, which successively forms the feed-in tariffs, transmission and distribution price and the final user price. The feed-in tariffs can be called generation price, that is, the ex factory price of the energy generated by the power plant, which reflects the scarcity of power generation resources and the cost difference. The power supply structure can be rationalized by adjusting it. The generation price is composed of generation cost, generation profit and price tax. Transmission and distribution price, also known as power grid price, refers to the price of electricity sold to the distribution company by the owner of high-voltage or ultra-high-voltage transmission or circuit. It is similar to the price of general goods sold to retailers and wholesalers. Therefore, it can also be used as a wholesale price to reflect the consumption of transmission and generation resources, to regulate the construction of transmission network, and to solve the allocation of power resources in rich and poor areas. The transmission and distribution price is mainly composed of power purchase cost, transmission and distribution cost, transmission and distribution profit and tax. The price of electricity sales refers to the price of electricity sold by distribution companies to end users. It is similar to the retail price of general commodities. It is also known as user price or retail price, which reflects the impact of users on the power supply cost. The final selling price consists of the cost of purchasing electricity from the power grid, the cost of power transmission and distribution, and the profit and tax of electricity sales.

1.Price-based DR

Price-based DR refers to users responding to changes in retail electricity prices and adjusting electricity demand accordingly. It mainly includes the following forms.

(1) Time-of-use pricing (TOU) is a price mechanism that can effectively reflect the difference of

power supply cost in different periods of power system. Its common forms are peak-valley price, seasonal price and flood season-dry season price.

(2) Real-time pricing (RTP) is a dynamic pricing mechanism. Its renewal cycle can reach 1 hour or less. By linking the price on the user side with the clearing price in the power supply market, it can accurately reflect the change of power supply cost in each period of the day and effectively convey the price signal. RTP can compensate for the shortage of incentive for users to further reduce load when the system is short-term capacity shortage.

(3) Critical peak processing（CPP）is a dynamic tariff mechanism developed on the basis of TOU and RTP. Its main idea is to superimpose peak charges on TOU.

1) Time-of-use (TOU) pricing is a price mechanism. It can effectively reflect the difference of power system cost in different periods. Its common forms are peak valley price, seasonal price and price in flood season and dry season.

2) Real-time pricing（RTP）is a dynamic pricing mechanism. It can be updated for an hour or less. By linking the price on the user side of the clearing price in the power market, the change of the power supply cost in each period of the day can be accurately reflected, and the price signal can be effectively conveyed. RTP can compensate for the lack of incentive and further reduce the load for users in the short-term capacity shortage of the system.

3) Critical peak pricing（CPP）is a dynamic tariff mechanism based on TOU and RTP. The main idea is to add the TOU peak fee.

2. Incentive-based

The incentive-based DSM refers to the DSM implementation agencies formulate corresponding policies according to the supply and demand situation of the power system. Users can reduce the demand for electricity when the system needs or power is tight, so as to obtain direct compensation or another preferential price. It mainly includes the following forms.

1) Direct load control(DLC) refers to the way in which the direct load control mechanism closes or controls the user's electrical equipment through the remote control device during the peak power consumption of the system.

2) Interrupt load (IL) is a method that interrupt request signals are sent to users during a part of electricity interruption period by interrupting load actuator according to the peak period of power grid before the contract between supplier and demander.

3) Demand side bidding (DSB) is an implementation mechanism in which demand side resources

participate in power market competition. It enables users to actively participate in market competition and obtain corresponding economic benefits by changing their electricity consumption mode, instead of simple price receivers.

4) Emergency demand response(EDR) refers to the way that users respond to the power demand of emergency interruption in an emergency.

5) Capacity auxiliary service program (CASP) is a form in which the user provides load reduction as a backup system instead of the traditional generator or provides resources.

These two types of DR projects have certain internal relations and can complement each other. For example, users can respond to price changes and make load adjustment through the implementation of DR project based on electricity price. So as to reduce the price peak and alleviate the shortage of system reserve, and further reduce the necessity of implementing incentive based DR project. Therefore, the complementation of each subcategory should be taken into account when the DR implementing agency formulates various DR projects. For example, PG&E company of California stipulates that users who participate in CPP can no longer participate in incentive based DR projects such as IL. Both DR and energy efficiency can achieve peak shaving, slow down the growth rate of demand and save electricity expenses of users. Therefore, these two resources can be collectively referred to as demand resources. From annual system planning to real-time market scheduling, DR can be flexibly deployed in different time scales, and participate in coordinating market pricing and system scheduling management.

1.3 Key technologies of measures on the technical side

The main areas of demand side energy consumption regulation are building fence structure, HVAC system and energy supply system. Among them, the green building evaluation system of various countries involves all the above fields, and the evaluation indicators are set for each key node of energy consumption on the demand side. At the same time, it is difficult to change the fence structure of the demand side after the construction. The demand side technology based on HVAC system and energy supply system is the main core of energy-saving technology transformation. Among them, the distributed energy system established by cocoa renewable energy and clean energy on the demand side has the most obvious effect and the fastest development.

At the end of the 20th century, the United States, the European Union, Japan and other developed countries have begun energy transformation and energy system reform. Although the social conditions and energy endowments of countries are quite different, they are all developing towards a more market-oriented, clean and intelligent direction.

The development trend of the power grid structure is: vigorously promoting the construction of the distributed energy with the integration of clean energy and renewable energy, and constituting a certain capacity of distributed energy with regional distribution network and its user load into a single controllable microgrid system. Connect and integrate these microgrids through smart grid to achieve the balance and optimization configuration of the entire power grid [18]. In the cell architecture theory put forward by Denmark earlier, the microgrid is compared to the cells. The instability of renewable energy is digested in the cell as much as possible, and then complementary relationship is formed with the large power grid. Under the guidance of this concept, in the past ten years, the research and technology of microgrid and smart grid have made great progress, and the distributed energy and renewable energy have been growing dramatically. In 2019-2040, under the established policies and sustainable development scenarios, the share of renewable energy in the new capacity of each region will be increased, as shown in Fig.1-8 [19].

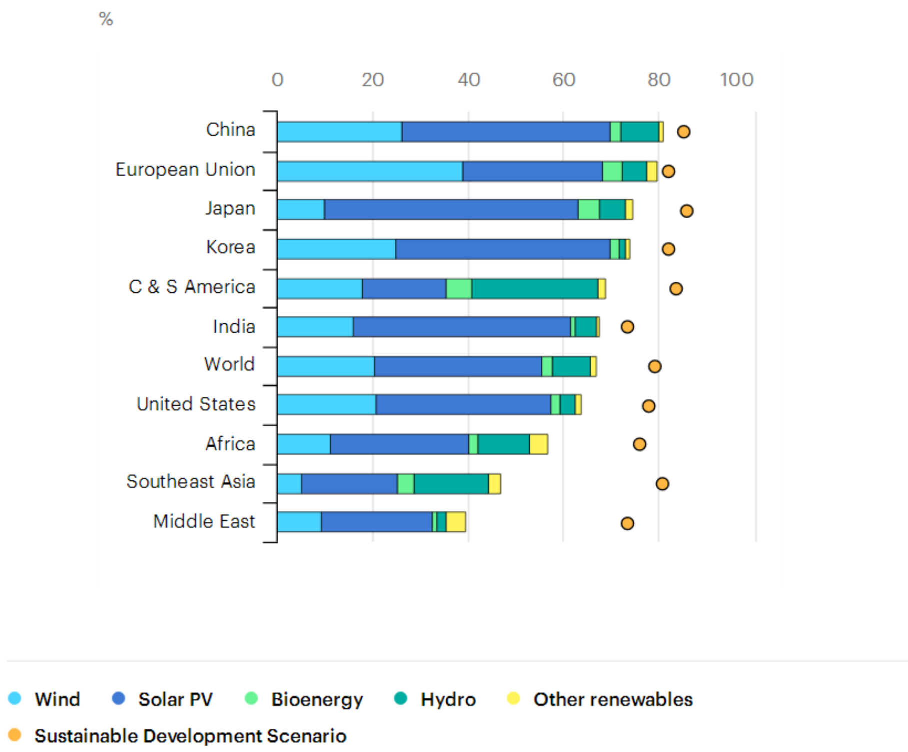

Figure 1-8 Renewables share in capacity additions by region in the Stated Policies and Sustainable Development scenarios, 2019-2040 [17]

The EIA estimates that global power generation will grow by 79% between 2018 and 2050. Population growth and improved living standards in non OECD countries, as well as demand for housing and personal equipment, will increase electricity consumption in the residential sector. With the popularity of electric vehicles and the increase of railway power consumption, the power consumption in the field of transportation has also increased. As shown in Figure 1-9, renewable energy will account for 49% of the world's total power generation by 2050. Resource availability, renewable energy policies, regional load growth, and declining technology costs have driven the EIA's expectations for solar power growth. Among the three renewable energy sources of hydropower, wind and solar energy, EIA believes that solar power generation shares the fastest growth, while hydropower growth is the slowest [20].

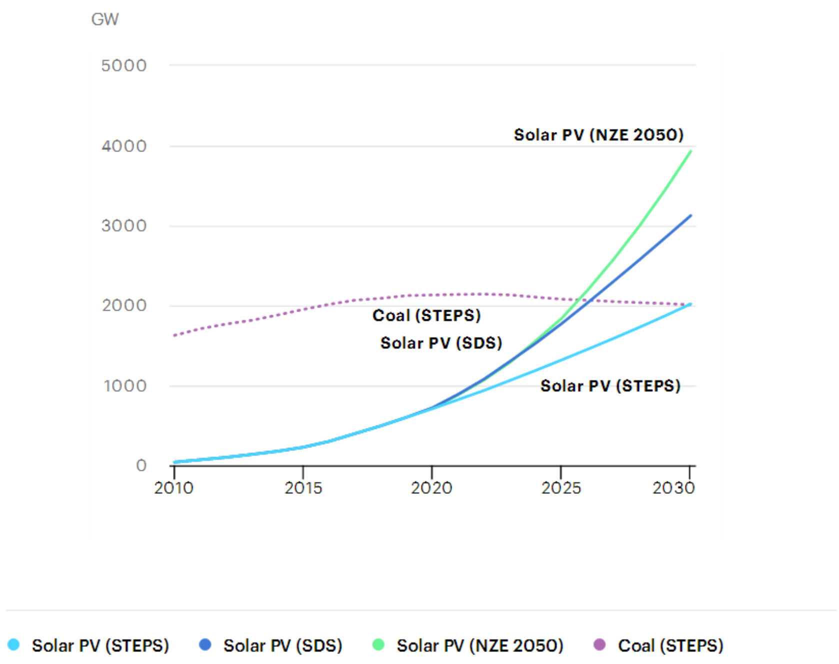

Figure 1-9 Global solar PV and coal-fired installed capacity by scenario, 2010-2030 [19]

By 2030, the total investment in renewable energy power is expected to reach $3.4 trillion. Among them, the investment in wind power and photovoltaic power generation projects will reach $2.72 trillion, accounting for more than 80% of the total investment. By 2030, the total installed capacity of renewable energy power, including hydropower, will account for 54.1% of the total installed capacity of all electric power, among which wind power and photovoltaic power generation will account for 37.9%. In the next 10 years, the global power sector will rapidly "decentralize". "In 2019, the global total annual investment in renewable energy power will be $53.1 billion; by 2030, this number will grow rapidly to US $92.54 billion. From the regional perspective, Asia, the Middle East and Europe will be the regions with the fastest growth in renewable energy power investment [21]. While the global renewable energy power development momentum is strong, coal power has been facing downward pressure. Traditional power plant operators need to show "extreme physical and digital flexibility" to compete with renewable energy power for a long time. Distributed energy system is to store the surplus energy produced by distributed generation in the energy storage equipment during the low power consumption period, release the surplus energy to the large power grid during the peak period of power consumption, realize the "peak shaving and valley filling" to ensure the dynamic stability of the grid load; assist power supply or transmission in case of power grid failure or natural disasters; ensure the power demand of users in the case of forced power failure or power supply interruption. Application of distributed energy in common fields is shown in Fig 1-10 [22].

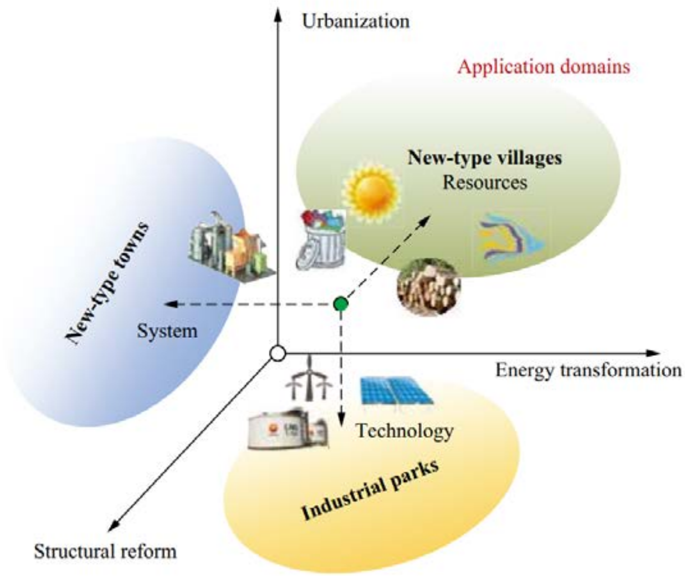

Figure.1-10 Applications of DER in three domains [21]

Power selling enterprises must carry out DSM, and DSM will gradually give consideration to energy-saving services. After that, user energy trusteeship and energy efficiency trusteeship will become a new profit model. At this time, the technical advantages of developing distributed energy in energy efficiency trusteeship will be reflected. Compared with other energy utilization modes, the residual heat generated by distributed natural gas power generation can be fully utilized. Its comprehensive efficiency is high, the transmission distance is short, and the line loss is less consumed. Meanwhile, the double peak shaving of electricity and natural gas can be carried out. The energy efficiency enhancement will promote the establishment of the energy internet and improve the competition service through the "Internet +".

The power grid is currently shifting from a market for the energy of seller to buyer, and the related management mode has also changed from the planned economic dispatching mode to the market-oriented management with the full participation of consumers, which is the future direction of the development of distributed energy. In the future, there will be a large number of distributed generation grid connected, including distributed photovoltaic or small energy storage power station. Small power supply will be aggregated through the microgrids to replace the large power supply, giving full play to the advantages of decentralization and intelligence [23]。

With the rapid development and construction of distributed energy, power demand side management will also develop rapidly. If the demand side power consumption can be interrupted, transferred and misappropriated during the peak period, it will provide a lot of energy space for the society. However, with the development of society, the demand side itself becomes the power generation side. Thus, the power supplier, consumer and user are the same one, so the technology, mechanism, power balance and other issues need to be addressed. The main force of DSM implementation is not only distributed energy, but also the comprehensive optimization of various energy sources, such as microgrid and large grid.

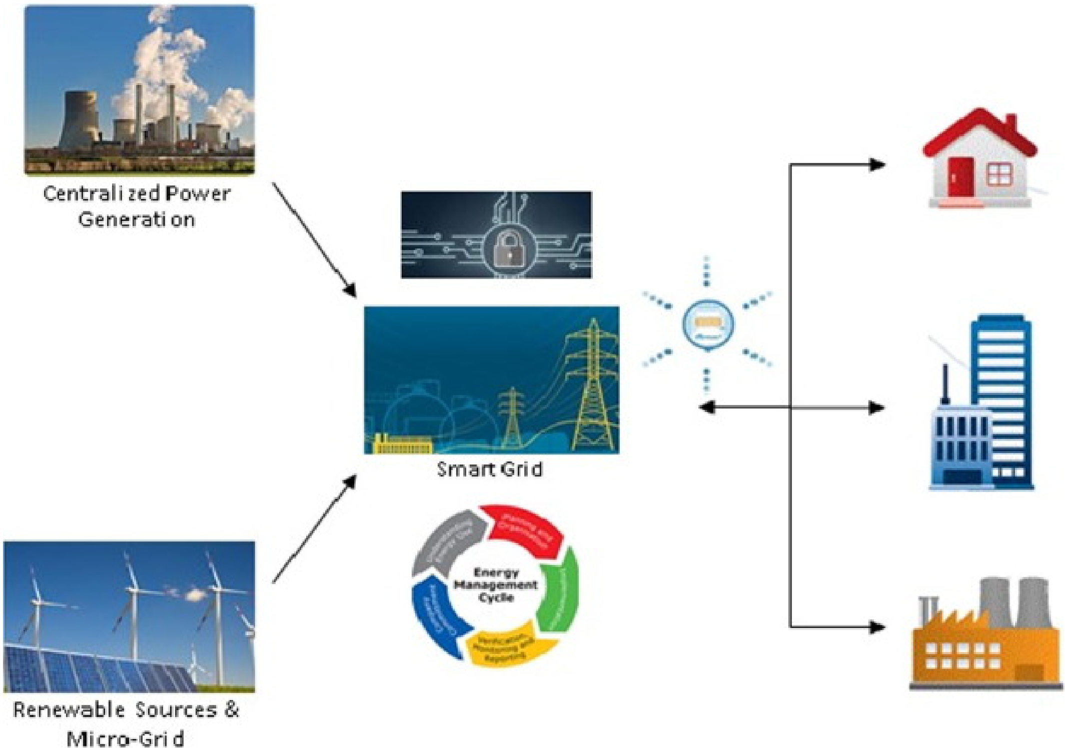

Figure 1-11 Working concept of Smart Grid [23].

The US Department of energy mentioned in grid 2030 that smart grid (as shown in figure 1-11) is a fully automated power transmission network, which can monitor and control each user and grid node, and ensure the bidirectional flow of information and power between all nodes in the whole transmission and distribution process from the power plant to the end user [24]. Smart grid and Microgrid technology are increasingly integrated with the Internet. Although the concept of Energy Internet has not been formally proposed, the de facto energy Internet has gradually formed. Since Boulder, Colorado, completed the first phase of the smart grid project in 2008, more states began to test run the smart grid. IBM, Google, Intel, Cisco, general motors and other giants joined in. IBM applied its own software and server to the smart grid system, and Cisco mainly focused on the network system connecting meters, converters, digital power stations and power plants Google has developed an application that uses electricity meters to save electricity. In Europe, Germany has established a nationwide electricity sales platform. At the beginning of 2015, there are more than 1000 power suppliers, which can provide more than 9000 kinds of power packages. Some companies are committed to developing new customized packages (such as industrial electrolytic aluminum packages, small city family of three packages, etc.), and some companies provide users with power package search and screening services. Such a division of labor has been very meticulous. In 2016, 42% of public electricity in California was renewable, which has led to solar curtailment, for example, in summer afternoons. Because the amount of solar power fed back to the grid is too much that the power companies can absorb. This will result in a "negative rate table", that is, if the grid is an used system, it will have a lot of capacity to handle additional energy when the power generation is insufficient, such as an excess of load. However, if too much renewable energy is fed back to the grid, the power companies cannot deal with it. The solution to the excessive load of renewable energy is to greatly increase the energy storage capacity. Some energy storage devices come out in the form of a large number of miniaturized household systems, so that people can improve their electricity bills. However, the biggest driving force of energy storage devices is the size of power companies. Many power companies have high renewable portfolio standards (RPS) goals, as shown in Figure 1-12 [25]。

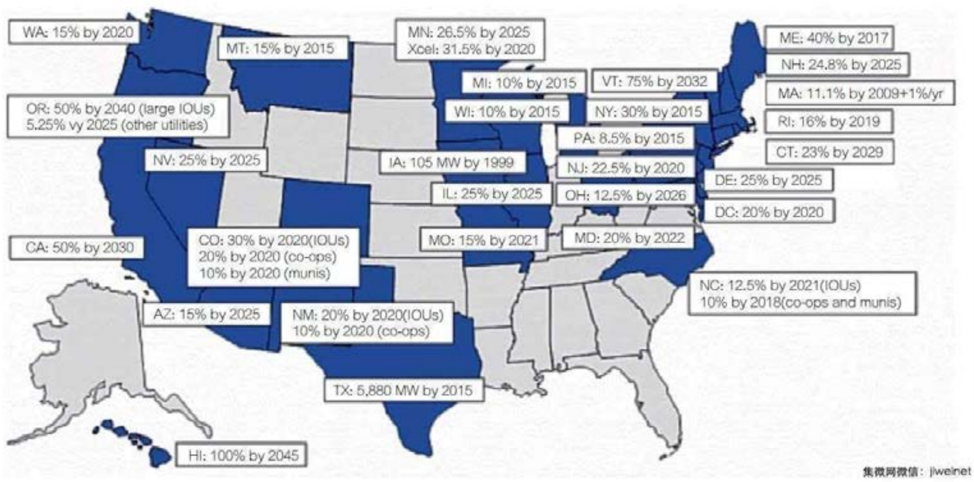

Figure 1-12：Renewable Portfolio Standards (RPS) strategy of 29 states and Washington D.C

The energy storage system keeps the hope of reducing the cost for the end users. At the same time, the generator is connected to the higher quality distributable power production by changing the time difference of power production. The energy storage system keeps the hope of reducing the cost for the end users. At the same time, the generator is connected to the higher quality distributable power production by changing the time difference of power production. By adjusting the load, absorbing the peak power, providing power when the power supply suddenly decreases, and storage local energy can alleviate the power fluctuations caused by renewable energy production and output. The smooth production curve can provide a more stable and reliable power source for the power grid. Some power companies have requirements for power generation equipment connected to the grid, which requires energy storage to adjust the waveform of power production. The utilization of energy storage system can help power companies to postpone the upgrading of basic load power stations, or delay the increase of new generation capacity, because the increase of new generation capacity will lead to the increase of cost index. At present, there are many ways to store energy, which depends on the specific application and the required system characteristics. Energy can be stored in the form of electric, mechanical, thermal or chemical storage systems, each with its own advantages and applications. Electric storage is the most common way, usually adopts battery or capacitor. From watch batteries to the latest lithium-ion batteries in data storage centers, and large-scale storage systems of power companies. According to the Research Report of Navigant research, the revenue of global distributed energy storage system reached $452 million in 2014, and it is expected to exceed $16.5 billion by 2024. The development of advanced chemical battery technology, including lithium-ion, liquid flow battery, lead-acid battery and other new generation chemical battery, will promote the rapid development of distributed energy storage system. These advanced battery technologies for DSM will help to meet the needs of distributed solar photovoltaic power generation, electric vehicles, charging piles and household energy networks.

1.4 Key technologies of measures on the economic side

The last decade， technological advances, structural market changes, regulatory intervention, and political influences has contributed to the capital integration of global power market and the continuous change of market rules [26]。

First, the electricity market-oriented reform presents the trend of globalization. As of 2009, 86.49% of the global population has experienced electricity market-oriented reform, and the total GDP of power market-oriented countries accounts for 94% of global GDP. No matter in terms of population, GDP share, national development status and continent distribution, there is no doubt that this round of reform is global. Although the background, path and effect of the reform in different countries are not the same, it has become a consensus that they all hope to improve the performance of the power industry and promote the economic and social development of their own countries or regions.

Second, the electricity market-oriented reform presents regional imbalance. The development progress and marketization degree of electricity market-oriented reform in different continents and regions are unbalanced, and the reform progress of countries in African and Southeast Asian is slow. Europe and Oceania are the two continents with the largest increase in the degree of electricity marketization. Europe, which has the majority of developed countries, has made good achievements in this round of power market-oriented reform. Not only has the score of power marketization reached 7.38, but also the score of power marketization degree has increased by 6.28 scores in this period. New Zealand and Australia in Oceania have opened up more quickly, up 6.75 scores from 1990 to 2009 owing to the spot and futures markets for electricity.

Third, the degree of electricity market-oriented reform is different under the level of national development. The basis of electricity marketization in developed countries is higher than that in developing countries. In 2009, the average score of power marketization in developed countries reached 6.96, while that in developing countries was 5.25 scores. However, there is no doubt that both developed and developing countries have improved rapidly, with 6.23 and 3.97 scores, respectively. However, there is still a big gap between developed and developing countries in the degree of electricity marketization.

Fourth, the degree of electricity marketization is positively correlated with the level of economic development. By observing the results of the polynomial regression fitting model between the degree of electricity marketization and the level of economic development of 98 countries/regions in 1990 and 2009, it can be seen that, compared with 1990, the influence of economic development of various countries on power marketization in 2009 is higher. By observing the fitting model of the impact of electricity marketization degree on per capita GDP in different countries, we can see that electricity marketization also affects economic development. When the degree of power marketization is low, the efficiency of the power industry cannot keep up with the speed of economic development, and even hinder the economic development. The state began to carry out the reform of power marketization. With the deepening of power market reform and the improvement of energy supply and distribution efficiency, the power industry began to promote stable economic growth within possible limits. Compared with 1990, with the market-oriented reform in most countries, the difference of power marketization degree among countries in 2009 is also gradually increasing, which results in the stronger impact of power marketization on the economy. At present, the continuous liberalization of the power market has become one of the main development trends to promote the power transformation. Power market liberalization is to improve market efficiency, reduce resource waste, reduce retail price and stimulate technological innovation by deregulation [27] and promoting benign competition. According to the experience of the United Kingdom and other countries since the beginning of deregulation reform in the 1990s, the main factors affecting the competitiveness and efficiency of the power market are local market power, market transparency, barriers to market entry, level of market risk management, sufficient price signals and market structure with appropriate incentives for investors [28]. It can be concluded as the game process between market power and supervision system.

An efficient regulatory system can attract investment in the power market, eliminate market power, reduce unfair competition and improve the profits of operators. The current regulatory system cannot meet these needs at the same time [29]. When the regulatory system is committed to reducing consumer electricity prices, the profits of operators, distribution companies and storage Investors [30] will be greatly reduced. When the regulatory system is committed to the elimination of market power, it will make the consumer price soar [31]. Therefore, while power market liberalization brings dividends to the society, there are also regulatory risks and the distribution of interests of all participants [32].

The development of artificial intelligence and blockchain technology not only promotes the process of power market liberalization, but also realizes the deep application of interdisciplinary technology in the process of power market reform. AI and blockchain technology, combined with Internet of things, GIS and BIM technologies, improve the transparency of electricity price trading by building a peer-to-peer (P2P) electricity trading trading system. It can reduce the time cost and economic cost of transaction, reduce the regulatory risk and improve the quality of supervision.

1.5 Development status of energy saving technology of DSM in Japan

In the 1970s, Japan began to vigorously implement power demand-side management (DSM). From 1973 to 2014, GDP increased by 2.4 times, but industrial energy consumption decreased by 10%. The level of energy saving reached the highest level in the world. In the 1990s, Japan began to carry out the demand resource (DR) technology research, but it was after the East Japan earthquake in 2011 that Japan started to implement DR technology.

In 1995, access to the power generation side was liberalized. Through public bidding, independent power generation enterprises "IPP" were allowed to be established, and "General Electricity Utilities" (GEU) could purchase electricity from IPPs. In 1999, the introduction of Power Producer and Supplier (PPS) to engage in the electricity sales business, can sell electricity to "ultra-high voltage" industrial and commercial enterprises. In March 2000, such large users accounted for 26%. In 2003, the freedom of users to choose power suppliers was further expanded, and "high voltage" small and medium-sized industrial and commercial users could choose power suppliers freely. By April 2004, 40% of users were free to choose. In April 2005, the proportion rose to 63%. In June 2014, Japan published its fourth Basic Energy Plan: in order to promote effective electricity saving on the demand side, with the steady progress of power reform, it is necessary to actively create conditions to introduce a new "demand response" mode, maintain a reasonable scale of power generation capacity and realize stable power supply through user side demand management. In June 2015, the "Japan Revitalization Strategy" clearly put forward a policy to promote VPP. Subsequently, the Ministry of Economy, Trade and Industry of Japan began an auxiliary business to try to solve this problem by remotely controlling the power generation equipment and batteries of factories and households. The goal of the project is to integrate all kinds of power sources into a unified power plant (Virtual Power Plant) to make it work. Therefore, the project is named as "demonstration of virtual power plant with active demand side energy".

In 2016, the "Japan Revitalization Strategy" formulated by the Japanese government proposed to achieve the goal of demand response accounting for 6% of the total power demand by 2030. With DR response electricity (power I-B) listed and traded on the wholesale market, 2017 is known as the "first year of DR" in Japan. The fifth Energy Basic Plan issued in July 2018 continued to clarify the speeding up of low-cost energy storage batteries, V2G (Vehicle to Grid), power-to-gas (P2G) technology promotion, and strengthening of low-power wide area network technology (LPWA) and M2M , P2P technology research and development to further promote the low-carbon power supply.

Due to the extreme power shortage caused by the Great Japan Earthquake in March 2011, the Japanese government has made great efforts to strengthen DSM by means of administrative and economic means. With the active cooperation of the whole society, power-saving actions have achieved remarkable results. During the summer peak power consumption period after the earthquake, under strict DSM measures, the maximum daily load of Tokyo Electric Power in summer decreased from 58.87 million kW in 2010 to 49.22 million kW in 2011, with a year-on-year decrease of 16.3%. In 2016, the demand response capacity of Japan Electric Power Company was approximately 10.7GW, of which 78% of the load was released. In 2016, seven demonstration projects in Japan received a total of 2.65 billion yen in subsidies. In April of the same year, the "Energy Innovation Strategy" formulated a government subsidy plan from 2016 to 2020, vigorously supporting enterprises to carry out VPP technology research and development. One of the key tasks is to verify the reliability of virtual power plants above 50MW, and plan to realize VPP economic independence by 2020. In December 2017, Nippon Power I realized unified regulation and control of power user-side load resources through bidding, and completed a response of 1.33 million kW throughout the year, of which DR reached 958,000 kW, with a value of about 3.6 billion yen. In 2017, six demonstration projects received subsidies totaling more than 6 billion yen.

After several rounds of electricity reform, Japan has gradually established a market operation mechanism based on the participation of DR and VPP in the futures market, day ahead market, hour ahead market and spot market. In the future, new electricity market mechanisms such as base load market, capacity market, non-fossil value market and auxiliary service market will be continued to establish and form. From May this year, the FIT green certificate will be traded in the non-fossil value market, and this market will also be open to all non-fossil energy sources in 2019. In order to promote new power companies to participate in the baseload power trading competition, Japan plans to create a baseload power market in 2019. The competitive power market also requires the establishment of a market mechanism for power capacity and capacity regulation. In 2020, Japan will launch a capacity market and create a demand regulation market. The competitive electricity market also requires the establishment of a market mechanism for power capacity and capacity regulation. In 2020, Japan will launch a capacity market and create a demand regulation market.

1.5.1 Energy saving method

Due to its "congenital deficiency" in energy resources, Japan attaches great importance to the conservation and utilization of energy, and its energy-saving work level is in a leading position recognized in the world. More than 90% of greenhouse gas emissions are carbon dioxide in Japan, and most of them come from energy. Electricity accounts for more than 40%. Of all greenhouse gases, about 30% comes from electricity.

If the potential of reducing carbon dioxide emissions before 2030 is classified by technology, we can get the following estimation. Energy saving can reduce about 60% of the world's carbon dioxide emissions and about 70% of the emissions of developing countries [33]. As a global warming against strategy, in the world tide of reexamining nuclear power plants after the East Japan earthquake, energy conservation is very effective, which, together with the possibility of renewable energy, has attracted worldwide attention.

In response to the two oil crises in 1973 and 1978, Japan enacted the Energy Conservation Act in 1979. Since the promulgation of the law, through the cooperated efforts of the government and the masses, the energy consumption reduction rate in Japan has increased by 37% in the past 30 years. This is mainly the result of a two-pronged energy conservation policy with restrictions on the industry and financial support. The government invested a budget of about 100 billion yen in the field of energy conservation only when the Energy Conservation Act was promulgated in 1979. In addition, a number of support policies have been introduced in the tax system, policy investment, and finance [34].

The composition of this Energy Conservation Act includes energy conservation standards for manufacturing plants, residential buildings, and machinery and appliances. This benchmark is revised every few years. Four energy-saving benchmarks were issued and strengthened including the factory business department (including business buildings, hospitals, shopping malls), transportation departments, residential buildings, as well as the mechanical appliances and automobiles in Top Runner Program (Top Runner). In order to meet the standards, the industry has formulated various autonomous action plans to save energy.

According to the Energy Conservation Act, factories and business departments have designated factories for energy management, and the scope of restrictions has also been expanded from manufacturing to business departments. In the 2005 revision, the transport industry was added to the regulations, and the shipper was also included in the scope of the regulations. In the residential construction sector, the content of the code is gradually strengthened. Especially in 1998 when the machinery department was revised to introduce the Top Runner Program. This sets a high level that must be achieved in the next few years. So far, standards have been set for 21 products including automobiles, home appliances, and lighting appliances.

For example, when the car Top Runner Program was announced in 1999, car manufacturers accepted this rather strict regulation. As a result, car manufacturers developed toward the set future target value, and competition among manufacturers occurred [35]. Regarding the achievement of the goal before 2010, Mitsubishi Motors announced in 2001 the ambitious goal of "achieving the plan by 2005". Other companies followed suit and announced plans to achieve the goal in advance and achieved the goal ahead of schedule. Figure 1-13 shows the total energy supply of the five countries in 2018 [36].

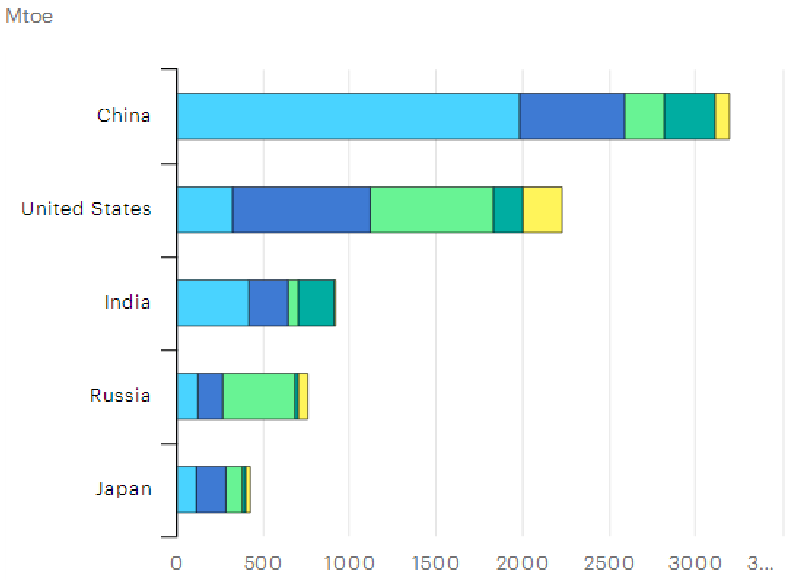

Figure 1-13 Top five countries by total energy supply by energy source, 2018

In 2015, the Japanese government announced its long-term energy supply and demand outlook based on the Strategic Energy Plan (2014). The outlook puts forward an ideal structure of energy supply and demand in 2030, which can be achieved if appropriate measures are taken to achieve the basic objectives of energy policy: security, energy security, economic benefits and environmental protection.

Energy efficiency and renewable energy play a key role in achieving all these goals by promoting energy independence, reducing oil and gas imports and reducing greenhouse gas emissions. Under the new plan, final energy demand will be saved by as much as 50.3 billion liters (crude oil equivalent) by 2030. Divided by industry, the transportation industry will save 1.607 million kiloliters, followed by the commercial sector with 1.226 million kiloliters, the residential sector with 1.160 billion kiloliters, and the industrial sector with 1.042 million kiloliters. These figures show that from 2012 to 2030, the final energy intensity needs to increase by 35%. In 2030, renewable energy power generation is 237-252 TWh, accounting for 22-24% of total power generation, solar photovoltaic power generation is 7.0%, wind power generation is 1.7%, and biomass power generation is 3.7-4.6%. Geothermal power generation is 1.0-1.1%, and hydropower generation is 8.8-9.2%.

In 2015, the Japanese government published the Long-term Energy Supply and Demand Outlook based on the Strategic Energy Plan (2014). This outlook presents the ideal structure of energy supply and demand for 2030 that can be realized if appropriate measures are taken to achieve the fundamental objectives of energy policy: safety, energy security, economic efficiency and environmental protection.Energy efficiency and renewable energy plays a key role in achieving all these objectives because they can contribute to energy independence, to the reduction of oil and gas imports and to the reduction of greenhouse gas emission.According to this new plan, the final energy demand should save as much as 50.3 billion litres (crude oil equivalent) by 2030. By sector, savings from transport will amount to 16,070 thousand kilolitres, followed by commercial at 12,260 thousand kilolitres, residential sector 11,600 thousand kilolitres and industry at 10,420 thousand kilolitres. Those figures indicate that 35% improvement of final energy intensity needs to be achieved from 2012 to 2030. Renewable electricity generation would be 237-252 TWh, and its share in total electricity generation would be 22-24% in 2030: solar PV 7.0%, wind 1.7%, biomass 3.7-4.6%, geothermal 1.0-1.1% and hydro 8.8-9.2%.

In accordance with the development of the world economy, changes in the energy environment, and energy-saving technological innovation, the Japanese government formulated the fifth Energy Strategic Plan in 2018. The plan puts forward the development plan and target for 2030: By 2030, the total energy consumption will be reduced by 43 million tons of standard oil. Clean energy utilization rate reached 44%, renewable energy power generation accounted for 22-24%, and energy self-sufficiency rate increased to 24%. Greenhouse gas emissions will be reduced by 26% in 2030 compared with that in 2013, and 80% by 2050, so as to realize the new goal of "low-carbon" to "decarbonization". Energy conservation and energy efficiency, to achieve an energy-saving society in an all-round way, to achieve 100% energy-saving popularization rate of circulation products by 2020 and 100% of energy-saving popularization rate of stock products by 2030.

Since 2003, the Japanese government required public building builders to submit mandatory energy-saving plan reports based on energy-saving standards. In 2005, the Japanese government began to require residential building builders to submit mandatory energy-saving plan reports. According to statistics from the Ministry of Land, Infrastructure and Tourism (MLIT), the submission rate of mandatory energy-saving reports in 2005 was 100%, of which 85% of public buildings met the requirements of the 1999 version of CCREUH at the design stage, while this figure was only 34% in 2000. A housing evaluation report based on the Housing Quality Assurance Law shows that 36% of newly built housing in 2006 met the requirements of the 1999 version of CCREUH.

On September 23, 2009, the Japanese government announced an energy-saving goal: By 2020, greenhouse gas emissions will be reduced by 25% compared to 1990. Based on the current state of end-use energy in Japan, building energy conservation is regarded as the most energy-saving potential field. Based on the latest goals, the Ministry of Economy, Trade and Industry and the Ministry of Land, Infrastructure, Transport and Tourism jointly established the "Building Energy Conservation Promotion Committee for Building a Low-Carbon Society", and in April 2012 passed the "Building Energy Conservation and Lifestyle Plan Roadmap for Achieving a Low-Carbon Society (Interim)", which mainly promotes the following four aspects of work:

1) Energy saving of new buildings. Discuss the steps and plans to enforce building energy efficiency standards by 2020, revise current standards of energy efficiency evaluation methods, promote zero-energy residential and public buildings, and establish low-carbon building certification.

2) Energy saving in existing buildings. Promote energy conservation and renovation of existing buildings through subsidies and adjustment of tax rates.

3) Renewable energy applications. Promote the large-scale application of solar photovoltaic, solar thermal, and geothermal energy in buildings.

4) Carbon reduction throughout the life cycle. Through the whole process of construction, operation and maintenance, demolition, recycling and other processes, CO_2 emissions during the whole life cycle of the building can be reduced.

In order to cooperate with the above-mentioned building energy-saving related work, the Japanese government has also launched a series of financial incentive subsidy projects. For example, the "Building Carbon Reduction Grant Project" and "Energy Saving Renovation Grant Project" launched in 2008; the "Environmental Residential Project" launched in 2009; in 2012, to promote the design and construction of residential buildings with the goal of zero energy consumption, the launch of " "Zero-Energy Housing Full Grant Policy", the total budget of related projects is 389 billion yen.

1.5.2 Top runner program

In order to promote energy-efficient machinery and appliances, the law on the rational use of energy (hereinafter referred to as the "Energy Conservation Act") requires manufacturers and importers to ensure that their products meet the energy-saving target standards. When Japan revised the law on the rational use of energy for the third time in 1998, it added a very important energy-saving management measure "Top Runner Program", which was implemented in 1999 [37]. The program aims to continuously improve the energy conversion and performance standards of the latest products. The leading standard adopted by the "Top Runner Program" is different from the minimum energy efficiency standard. The highest energy efficiency level in the current market is set as the energy efficiency target value of the product. When the target year reaches, the new target energy efficiency value will be reset. Manufacturers are given some flexibility, and products below the target energy efficiency value can still be sold in the market. The products involved in the "Top Runner Program" focus on increasing energy consumption in residential, commercial and transportation sectors, focusing on improving the energy efficiency of machines and equipment.

The energy-saving standards of equipment in various fields in Japan are mainly based on the Top Runner standard, which is mainly composed of six parts: product range (differentiation), target year, target reference value (energy efficiency limit value), measurement/measurement method, determination method of benchmark value achievement rate and label. The range and type of products are determined according to the energy consumption, usage, relevant testing standards and testing capability. The target year is determined on the basis of fully considering the social demand of energy consumption and energy efficiency level, product development cycle, investment and construction cycle of facilities and equipment, and the development prospect of high-efficiency and energy-saving technology in the future. The target year of different types of products can be different, generally set as 4-8 years. The target benchmark or limit value is determined by product classification according to the current maximum energy efficiency value and energy efficiency level improvement potential, which can be numerical or non-numerical calculation formula.

The "Top Runner" standard is voluntary, but if the products of manufacturers and importers are too far from the " Top Runner " standard, the Japanese Ministry of Economy, Trade and Industry (METI) will take measures to intervene, including reviewing and providing suggestions for improvement. Manufacturers must comply with METI's recommendations, otherwise they will be punished by warnings, announcements, orders, and even fines.

Currently, there are 23 kinds of products targeted by the "Top Runner Program", including passenger vehicles, freight vehicles, air conditioners, refrigerators, freezers, rice cookers, microwave ovens, fluorescent lights, compact fluorescent lights, electronic toilets, and televisions. , Video recorders (VTR), DVD burners, computers, disk drives, copiers, gas oil appliances (stoves, gas cooking appliances, gas water heaters, oil water heaters), vending machines, routers, transformers, etc. Japan has also implemented an energy efficiency labeling system for 16 products including air-conditioning equipment, refrigerators, televisions, electronic computers, transformers and microwave ovens. Among them, the electricity consumption of air conditioners in Japan is 1/2 of that of the United States, and refrigerators are 1/3 of that of the United States. Compared with ten years ago, the power consumption of Japanese air conditioners has decreased by 50-70%, the power consumption of Toshiba's series air conditioners has decreased by 75%, and the power consumption of Panasonic's latest energy-saving refrigerator has decreased by 85% [38]。

With product updates and technological advancements, the energy efficiency of products is investigated once a year. When products that meet the efficiency standard value of Top Runner increase by 30% compared to when the standard was established, the energy efficiency standard value of Top Runner will be re-established, and the standard will be adjusted on April 1 every year.

The main participants in the "Top Runner System" include the government, manufacturing companies, retailers and consumers. In order to ensure the smooth implementation of the "Top Runner program", different incentives and restrictive measures have been adopted for different participants. Manufacturing enterprises are the main body of the implementation of the " Top Runner program", and there are both incentives and restraints for manufacturing enterprises.

The “Top Runner Program” has achieved remarkable results. It not only effectively stimulates market competition and innovation, and promotes the application of existing energy-saving technologies, but also can continuously enhance industry competition and pursue the highest standards of energy-saving. The energy-saving standards for equipment in various fields in Japan are mainly based on the Top Runner standard. Voluntary energy-saving labels and mandatory retail electrical energy-saving labels are all established on the basis of the Top Runner standard. The "Top Runner Program" has become the world's most One of the successful energy-saving standard marking systems.

1.5.3 FIT plan

After the 311 earthquake and Fukushima nuclear disaster, the nuclear energy policy in Japan was spurned by the public and turned to renewable energy development. In addition to the government's immediate budget for the installation of 1GW solar roof in the northeast of the earthquake stricken area, Japan also accelerated the assessment of the acquisition of renewable energy at a fixed price. At the end of April, the "Procurement Price Determination Committee" of the Ministry of economy, industry and industry, which is responsible for setting the purchase price of renewable energy, calculated the purchase price of renewable energy, has set the price of electricity generated by solar power generation (FIT) at 42 yen (tax inclusive) / kWh, and the acquisition period will be 20 years. The "renewable energy special measures act" is the highest solar photovoltaic wholesale purchase rate in the world [39]. FIT is the government's commitment to purchase electricity generated by solar energy at a more favorable price within 10 years. Allowing households that invest in solar power to sell electricity to the government at a price much higher than the market price. In addition to subsidizing the high cost of installing solar systems in the early stage, the reduction in electricity bills and income from selling electricity after the cost recovery are equivalent to a considerable investment income [40].

If compared the bulk purchase rates of other countries, considering that European countries including Germany [41], Italy, France and other countries have reduced the bulk purchase rates [42]. In terms of 1MW power plants, the electricity buyback rate of Germany is about $0.7884, and that of Italy is about $1.003816. Therefore, compared with 0.4012 yen in Japan, it is indeed quite attractive.

Japan has accelerated the construction of solar photovoltaic systems. Along with other markets will transfer subsidies to roof type devices, Japan is going against the same path Instead, Japan has accelerated to encourage the construction of large-scale system power plants, especially in the reconstruction area. By the end of 2011, more than 50 MW power plants have been planned to be set up and will be connected to the grid for power generation [43].

1.5.4 Electricity market liberalization in Japan

Since 1951 after the Second World War, the Japanese power industry has been in a state of regional monopoly of large power companies (nine major power systems). In the 1990s, the electricity price in Japan is higher than those of European and American countries that carried out electricity market reforms. In order to curb excessively high electricity prices, Japan began to discuss introducing a competition mechanism in the power industry and gradually deregulating the electricity market. The reform of electricity market is mainly affected by two factors: one is the rapid appreciation of the yen, the hollowing out of the industry, and the excessively high electricity prices, which caused constant calls for reform. The other is the impact of the power market reform in the United Kingdom, the United States and Australia. The power industry in these countries has increased supply capacity and reduced electricity prices through deregulation, breaking of monopolies, and introducing competition mechanisms. Japan's electricity system has gone through several rounds since the 1990s, mainly involving the following aspects:

(1) The first round of electricity system reform: relaxation of power generation control;

(2) The second round of electricity system reform: relaxation of power sales business control.

(3) The third round of electricity system reform: further relaxation of power sales business control.

(4) The fourth round of electricity system reform: supply stabilization and effective competition.

(5) The fifth round of electricity system reform: First is fully liberalizing the power retail market, the second is the neutrality of the power grid.

Among them, the fifth round of reform is divided into three phases. The specific implementation time of each phase is shown in Table 1-1. The first phase of the power market reform: "the Organization for Cross-regional Coordination of Transmission Operators, Japan" (OCCTO) responsible for coordinating the trans regional power transmission dispatching in Japan was established to expand the use of wide-area systems and allocate power resources on a larger scale. OCCTO was officially launched in 2015. The main functions of OCCTO are: First is compiling and reviewing the power supply and demand plans as well as grid plans of various power companies, order power companies to change plans, such as the construction of interconnection lines; second is ordering power companies to generate and transmit power forcibly when power supply is emergency.

The second stage of the electricity market reform: completely liberalizing the electricity retail market and achieving full marketization. Since April 2016, the development of the generation side and the electricity sales side has been implemented, and companies in other industries such as natural gas, oil refining, and telecommunications are encouraged to actively participate in the power generation business, and they are encouraged to directly sell electricity to household users through the grid. At present, this reform has entered a period of substantial operation.

The third stage of power market reform: legal separation of power transmission and distribution systems to ensure the neutrality of the power grid. In April 2020, the separation of power plant and power grid was carried out to realize the legal separation of power transmission and distribution system. The generation department is separated with the transmission and distribution departments in law. A neutral transmission and distribution platform was established to let all power generation companies compete fairly when sold up to the grid. The regulation of electricity price is cancelled and the retail price is decided by the market.

Table 1-1 Specific implementation time of each phase of fifth round electricity market reform in Japan

Date		Content
2015	4.1	The first stage of electricity market reform: an organization for operation and promotion of electric power wide area was established, and started to work.
	7.31	Recognition application period for the transmission price and distribution price contracts
	8.3	Start accepting applications for registration of electric power retail companies
	End of December	Complete the review and confirmation of transmission price and distribution price
	12.28	Deadline for submission of island power supply contracts and power final guarantee supply contracts
2016	From January	Start accepting the replacement of electricity retail enterprises by electricity users
	4.1	The second stage of the electricity market reform: power retail is fully liberalized
2020	4.1	The third stage of electricity market reform: separation of power transmission and distribution departments by law and deregulation of retail electricity prices

In April 2016, Japan fully liberalized the electricity market and introduced competition to all users, and the electricity market became more vibrant. At that time, the electricity demand of more than 400 deregulated electricity retailers jumped by two-thirds. These power retailers, which are different from the vertically integrated regional power companies, have different enterprise foundations. The largest ENNET is a joint venture established by two natural gas distributors, Tokyo Gas and Osaka Gas, and NTT Facilities. NTT Facilities company is working on the development and power management of the renewable energy, which represents its telecommunications parent company, NTT. ENNET has been particularly successful because of its power generation assets and the ability to sell electricity to cost-sensitive commercial and industrial users.

According to the data as of mid-June 2016 (as shown in Table 1-2, less than 2% of the households abandoned the large-scale power companies in the past and choose new-type power retail companies, only 1.15 million households, accounting for a small proportion. However, it can be expected that power services will become diversified as the setting of electricity charges commensurate with the lifestyle and the possibility of operators who leave nuclear power and specialize in natural energy. And the number of households switching to retail power operators will continue to increase [44]。

Table 1-2 The number of contracts for households that change electricity companies

Electricity company	Number of contracts that change electricity companies
Hokkaido Electric Power Company	55800
Tohoku Electric Power Company	22100
Tokyo Electric Power Company	713300
Chubu Electric Power Company	75700
Hokuriku Electric Power Company	2600
Kansai Electric Power Company	237400
Chugoku Electric Power Company	2900
Shikoku Electric Power Company	5100
Kyushu Electric Power Company	43200
Okinawa Electric Power Company	0
Total	1158100

(Source: Official website of Electric Power Wide Area Operation Promotion Agency, data as of June 17)

Japan's electricity reforms have brought lower power prices to Japanese companies and people. According to statistics from the Ministry of Economy, Trade and Industry of Japan, from 1994 to 2004, the average domestic electricity price in Japan decreased at an average annual rate of 1.8%, and a total of 16.9% in the ten years. After Japan implemented the electricity market reform, although the cost of power generation fuel and international energy prices have risen sharply, the electricity price in Japan has dropped significantly. According to statistics, the electricity price level of TEPCO in 2005 was 27% lower than the electricity price level in 1996. TEPCO also took measures to actively reduce the grid transmission fee. In 2005, the grid transmission fee for high voltage users dropped by 23.2% compared with March 2000, the transmission fee for medium voltage users dropped by 13%. According to other statistics, in 1999, before the opening of the electricity-selling market, Japan’s industrial electricity price was 3.7 times that of the United States, 2.22 times that of the United Kingdom, 2.5 times that of Germany, 1.66 times that of Italy, and 3.12 times that of South Korea. But In 2003 after the electricity market reform, the industrial electricity price was only 0.83 times that of Italy. Compared with other countries, Japan's industrial electricity price has also been greatly reduced. Since 1995, the Japanese government has been promoting the liberalization of electricity and urban gas, starting with large-scale factories and other large-scale users. Judging from the current liberalization rate, in addition to facing households, electricity is 62%, while gas is 64%. Until the end of the day, the household market still maintains the regional monopoly of power and gas giants. However, by 2016, the household electricity market of about 8 trillion yen will be liberalized. In 2017, the household gas market of about 2 trillion yen will be liberalized, and the reform has entered a critical stage.

In Japan, the original market structure has been broken due to the addition of new power suppliers. The General Electric Power Utilities Company and Independent Power Producers provide power supply to users through the transmission network. The sales department, power sales company and power generation company of general electric power company constitute the main body of power market sales. After the electricity reform in Japan, the original ten general electric power companies generally feel greater competition pressure, and about 60% of consumers have re-selected electricity sales companies. Taking TEPCO as an example, after the deregulation of the electricity sales market, the number of its power customers has decreased sharply. The number of TEPCO customers' contracts has decreased from 2.84 million in 1995 to 1.71 million in 2017, a decrease of nearly 40%. Every further step in the reform of the Japanese power market must first be revised to the Electric Business Act. Law is an important guarantee for the smooth progress of power system reform. In fact, revising the law first and reforming electricity later is also a common practice in countries that have implemented electricity market reforms relatively smoothly.

1.6 Research structure and logical framework

1.6.1 Research purpose and core content

The research logic of the article is shown in Figure 1-14 below. Based on the demand of energy conservation and emission reduction, the core of the research is the technology means of DSM. The implementation and effect improvement of technology means promote the development of energy conservation and emission reduction on the demand side. The promotion of technology means is affected and restricted by economic means. Finally, the adaptability of demand side and technology means with different characteristics under the restriction of economic means is studied.

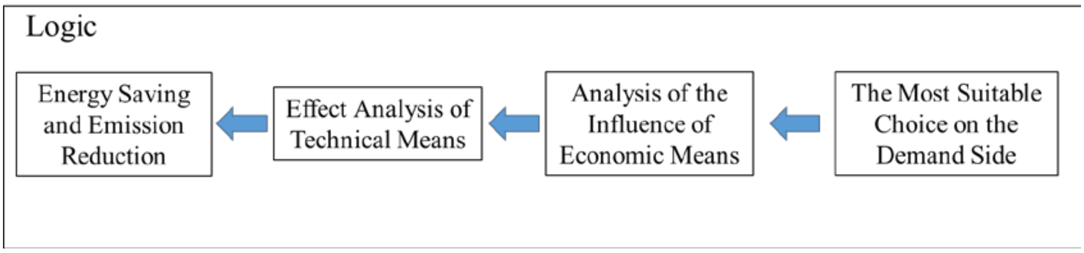

Figure 1-14 The research logic of the article

1.6.2 Chapter content overview and related instructions

The main content of this paper is shown in Figure 1-15. This paper takes the technology means of DSM as the research object, including equipment energy efficiency improvement and user load control. This paper studies from three aspects: policy promotion, economic impact and demand side adaptability. The specific chapter division of the article is shown in Figure 1-16.

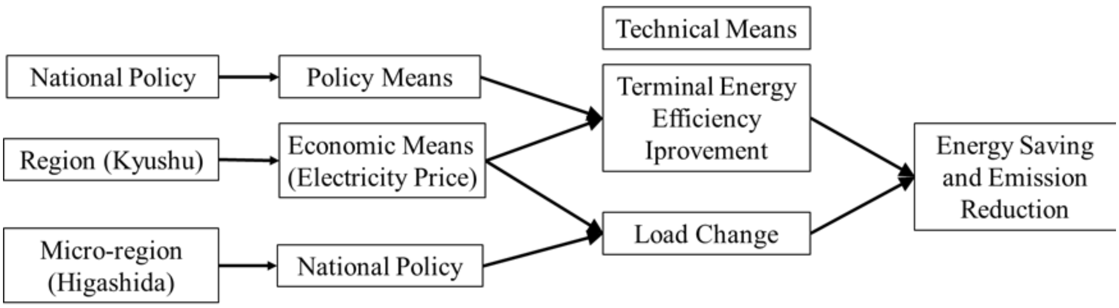

Figure 1-15 The main content of this paper

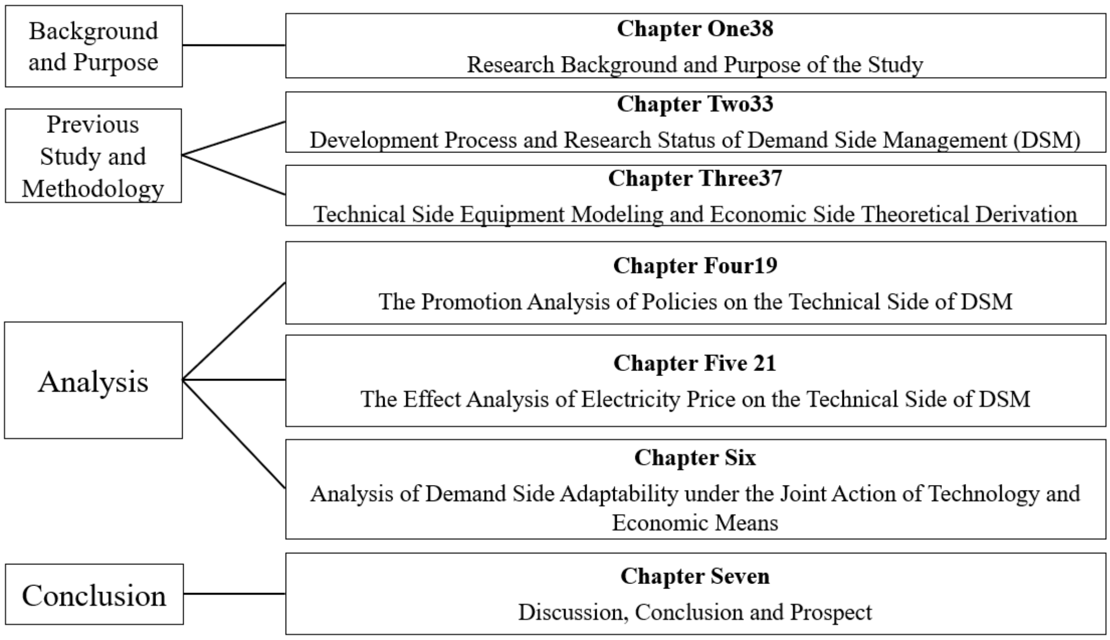

Figure 1-16 The specific chapter division of the article

In Chapter 1, Research Background and Purpose of the Study:

The growing power demand is putting more and more pressure on the global power grid operation and regulation, which gives birth to the urgent demand for DSM. This part combs and expounds the technical means and economic means of DSM, and puts forward that the core of the development of the two means in the current environment is the promotion of distributed energy and the liberalization of electricity market. Then, as the research objective of this paper, Japan's DSM, energy-saving technology development, relevant policies and electricity market development are fully combed. Finally, the logic and content of this paper are explained.

In Chapter 2, Development Process and Research Status of Demand Side Management (DSM):

This part mainly reviews and summarizes the development process of DSM and electricity market liberalization. At the same time, the research status of DSM is summarized from the following aspects: the technology side changes the way users use electricity and improves the energy efficiency of equipment; the response based on price, the response based on incentive and the correlation between the demand side and the electricity market; the application of machine learning, blockchain and internet of things in DSM. Through systematic and detailed research, this paper lays the foundation for the full text research.

In Chapter 3, Technical Side Equipment Modeling and Economic Side Theoretical Derivation:

This part has carried on the complete theory comb to the DSM. Firstly, the load characteristics of the demand side are studied, and then the characteristics of typical energy consumption and energy supply equipment in the technical side are analyzed and modeled. Then, different electricity prices and price reward and punishment mechanisms are modeled. Finally, a collection strategy with dynamic reward and punishment mechanism is proposed and the corresponding theoretical derivation is carried out.

In Chapter 4 The Promotion Analysis of Policies on the Technical Side of DSM:

In this part, a method of identification and evaluation of EEEIP was proposed, and the application was verified by analyzing the example of EEEIP in Japan (Top Runner policy, TRP). Firstly, through the factor decomposition model, this paper studied the energy conservation and emission reduction potential of this policy area in Japan. Then, the TRP was identified by using moving windows and correlation analysis, and the impact of specific equipment in TRP was analyzed. Finally, through the calculation of the rebound effect of the carbon footprint (REC), this paper analyzed the energy consumption and emission reduction effects of TRP in the short-term and whole life cycle. It showed that the policy has a good effect in tertiary industry and transportation, while the effect in residential is poor. For life cycle, the TRP of air conditioning and passenger car can bring better CO2 emission reduction effect, but the emission reduction effect of lighting is basically offset.

In Chapter 5, The Effect Analysis of Electricity Price on the Technical Side of DSM:

In this part, the interaction between electricity price and demand side is discussed. Firstly, through curve fitting and correlation analysis, the influencing factors of annual average retail price and wholesale price are studied. Then, through the combination of moving window and machine learning prediction, the volatility of hourly wholesale electricity price is discussed. Next, through the energy simulation of residential, the paper studies the effect of energy efficiency improvement of lighting, air conditioning and domestic hot water in different electricity price modes. Finally, the economic benefits of energy storage battery system with different time of use price difference between peak and valley are studied.

In Chapter 6, Analysis of Demand Side Adaptability under the Joint Action of Technology and Economic Means:

In this part, demand side buildings with different load characteristics are proposed as load aggregators to explore the optimal configuration and load adaptability of microgrid systems that can participate in V2G services under different demand side liberalization scenarios. Firstly, a smart community in Kitakyushu, Japan, is selected as the research object. By reducing the dimension of 49 different types of buildings in the region, six representative typical clusters are obtained. Then, Monte Carlo is used to simulate the permissible discharge capacity of V2G services. Then, three kinds of demand side liberalization situations are proposed, including self use, photovoltaic(PV) grid price and free trade, and the system configuration is optimized under different scenarios by genetic algorithm. Finally, combined with the load characteristics of different clusters, the load adaptability of microgrid in different liberalization scenarios is studied.The results show that the most suitable scenario is shopping malls, and the other two scenarios are the most suitable for office buildings with more gentle load changes. It is hoped that the research results can provide a theoretical reference for the future V2G service object selection and large-scale promotion.

In Chapter 7, Discussion, Conclusion and Prospect:

This part discussed and summarized the research of previous chapters. And based on the conclusions, the future development of DSM and the prospect of further research are put forward.

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Chapter 2

DEVELOPMENT PROCESS AND RESEARCH STATUS OF DEMAND SIDE MANAGEMENT (DSM)

CHAPTER TWO: DEVELOPMENT PROCESS AND RESEARCH STATUS OF DEMAND SIDE MANAGEMENT (DSM)

2.1 The development of DSM in typical countries

2.1.1 DSM development in Europe

There are eight regional electricity markets in Europe, each with different market rules and technical standards. There is no integrated DR implementation plan, so the DR projects carried out by European countries are mainly based on their own plans and rules. According to statistics, the average DR projects in European countries can reduce the peak load by 2.9%. The implementation mode of DR in typical European countries is shown in Table 2-1.

Table 2-1 Implementation mode of DR in typical European countries

Country	Project Type	Implementation mode
UK	TOU	Multiple rates
	IL	Interruptible load contract forms include: short-term operation reserve, fast standby, stable power grid frequency response.
Norway	IL	According to the advance notice time and the interruption duration, it can be divided into the following categories: ① 15 minutes in advance, the interruption duration is not limited, and the load is reduced by 5%; ② if the notice is given 2 hours in advance, the interruption duration is not limited, and the load is reduced by 25%; ③ if the notice is given 15 minutes in advance, the interruption time lasts for 2 hours, and the load is reduced by 75%.
	DSB	Norway has also developed a power frequency modulation capacity market. Demand side resources can compete with generators to achieve frequency regulation and power balance.
Finland	IL	Finnish power grid obtains power demand side resources by signing annual bilateral agreements with industrial users, which are used as frequency modulation reserve and fast reserve.
Spain	TOU	TOU price includes six different periods: peak and average price in peak season, peak and average price in medium season, and average and valley price in low season.
	IL	According to the advance notice time (0-2h) and interruptible duration (1-12h), the contract can be divided into five different types.
France	TOU	For users whose electricity load is more than 9kw, the TOU price is determined by the marking color (red price is the highest, white is the second, blue is the lowest) and peak valley period. Among them, the highest price in red peak period is 0.517 EUR/kWh, and the lowest price in blue valley is 0.057 EUR/kWh.

Ecogrid EU project is known as the model of smart grid development in Europe in the future. The focus of the project is that it allows small capacity distributed generation and end users to participate. Contrary to the existing electricity quotation, Ecogrid EU market is a real-time market without quotation. The operators of real-time market set the real-time price with 5-minute interval, and the small capacity distributed generation and end-users will make a response to provide balanced resources according to the received real-time price. The corresponding electricity market in different time periods is shown in Figure 2-1. The Ecogrid EU market concept in the context of the current (Nordic) electricity markets and system operation: shift to shorter time scales and more Volatility.

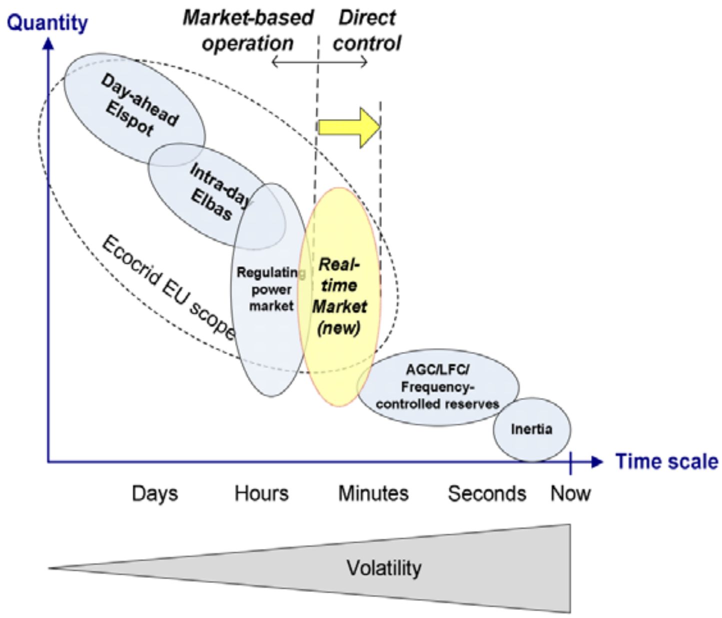


Figure 2-1 Electricity market corresponding to different time periods of the Ecogrid EU project.

The future power system will be connected with a large number of renewable energy, which brings great challenges to the operation and control of the system. The existing power infrastructure needs to be updated and strengthened to cope with the grid fluctuations detected in the process of renewable energy consumption.

2.1.2 DSM development in the U.S.

Energy saving and other energy-saving problems in the United States have led to the energy-saving crisis in the United States and other countries. In the spring of 1978, the Federal Energy Regulatory Commission (FERC) formulated a series of energy-saving policies and regulations, requiring state-owned and private power enterprises (including state-owned and private-owned) to implement "least cost plan (LCP)" and "demand side management". Among them, the most significant implementation effect is the "standard practice for cost benefit analysis of DSM programs" formulated by California Public Power Commission in 1983. The DSM process in the USA is shown in table 2-2.

Table 2-2 DSM process in U.S.

Time	Content
1970s	First start DSM, introduce direct load control project to deal with the soaring energy demand.
1990s	In response to the impact of the reform and restructuring of the U.S. electric power industry, a system benefit charging system was established in DSM. In 1996, the Federal Energy Regulatory Commission Order No. 888 released the binding of electricity and power generation wholesale market with transmission services, enabling energy customers to arrange and reserve regional grid capacity in the wholesale market, paving the way for demand side response to participate in the competition in the wholesale market
2003	Cascading blackouts in California promote the government, scientific research and industry to pay attention to demand side response.
2005	The energy policy act encourages time-based pricing and other forms of DR, and requires the allocation of necessary technologies to eliminate barriers to access to the energy, capacity and ancillary services markets, so as to benefit all components of the power units in the same region, and incorporate DR into the national policy.
2006	Nyiso, isone, PJM and other ISO introduce DR into auxiliary market.
2009	Federal Energy Regulatory Commission order 719 allows DR to bid directly in the wholesale market, which helps improve the competitiveness of the wholesale electricity market.
2011	The national action plan of demand response was issued to raise the DR to the national level.
2012	Openadr 2.0A released by openadr alliance is released as a national standard.
2016	The Supreme Court made it clear that resources such as demand response are equivalent to power generation resources.

In the late 1980s, more than 1300 DSM projects were implemented in the U.S., with peak load reduction of 0.4% - 1.4% and load growth rate of 20% - 40%.In the decade from 1985 to 1995, more than 500 power companies introduced DSM projects and reduced peak load by 29GW. By the mid-1990s, American power companies' investment in DSM increased year by year, from $9 billion in 1990 to $2.7 billion in 1994, accounting for 1% of sales revenue from 0.7%.

In the 1990s, many power enterprises were required to carry out DSM projects before the restructuring of the power industry. In 1992, the National Legislative Council strongly demanded that IRP and DSM should be included in the national energy policy action act. Due to the uncertainty brought about by the restructuring of the power industry, DSM projects have declined significantly, and the total expenditure (such as energy efficiency improvement and peak shaving) of American power companies for DSM projects has been reduced by more than 50%.

In the United States, at least 20 states have established state-level DSM project funding mechanisms. In 2000, the total revenue of these projects was 75 million US dollars. From 1998 to 2001, California raised a total of $872 million in system benefit fees, which has been extended to 2012 projects. In 1998, California's system benefit charging raised $173 million in DSM, saving 582 GWh of electricity, equivalent to a 0.6% reduction in electricity charges per user.

The Energy Policy Act (EPACT) of August 2005 clearly provides strong support for the implementation of DR. In February 2006, the U.S. department of energy submitted a research report on DR to the U.S. Congress, which elaborated the benefits of DR implementation and related suggestions. In August 2006 and September 2007, the Federal Energy Regulatory Commission (FERC) submitted DR annual reports to the U.S. Congress, systematically analyzed the background and status of DR implementation, the impact of DR on the system, and the application of advanced metering infrastructure (AMI-Advanced Metering Infrastructure) in DR.

In 2009, EPRI conducted a study on energy efficiency and demand response potential. According to the study, U.S. electricity consumption was 3717 billion kWh in 2008, and it is estimated that the annual electricity consumption in the United States will increase by 26% to 4696 billion kWh by 2020. The direct effect of demand response in the United States is that the U.S. has put forward four schemes: conventional, extended, realizable and full participation. Under these four schemes, the peak load can be reduced by 4%, 9%, 14% and 20% of the peak load respectively by 2019, as shown in Figure 2-2. The peak load reduction of the full participation scheme is equivalent to the 10-year electricity demand growth in the U.S..

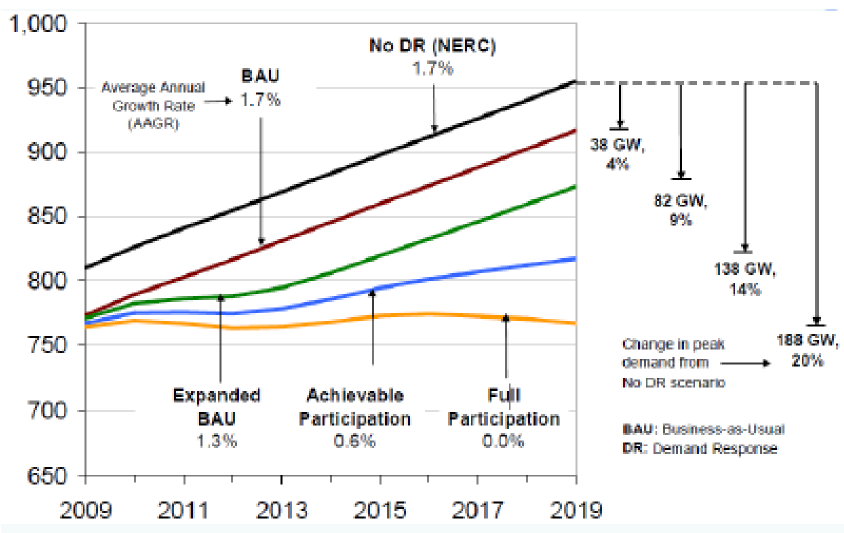


Figure 2-2 DR to peak load reduction in the U.S. by 2019

2.1.3 DSM development in China

DSM was introduced into China from the U.S. and Europe in the early 1990s. From 1991 to 2010, China has achieved a total electricity saving of 280-300 billion kWh, and the maximum transfer load is more than 30 million kW. Energy saving is over 100 million tons of standard coal. The development of DSM in China can be divided into three stages, as shown in table 2-3.

Table 2-3 Three stages of DSM development in China

Stage	Time	Content
Introduction of communication stage	1993-2003	In June 1993, the resource department of the State Planning Commission set up a project and entrusted the Energy Research Institute of the Chinese Academy of Sciences of the State Planning Commission to cooperate with the Shenzhen Energy Corporation, and completed the first pilot study in Shenzhen at the end of 1993.
Preliminary application stage	2004-2009	• In 2004, the government issued the guidance on strengthening DSM; • In 2005, the national development and Reform Commission and the Ministry of Finance jointly launched the Guangdong energy efficiency power plant pilot project with the loan from ADB; • In 2008, the national development and Reform Commission, the Ministry of Finance and State Grid Corporation jointly issued the notice on carrying out the comprehensive pilot project of DSM in Suzhou, Jiangsu Province.
Initial implementation stage	2010-So far	• In May 2011, the Ministry of industry and information technology issued the "urgent notice on doing a good job of DSM in the current industrial field"; • In November 2011, the national development and Reform Commission also issued the "power grid enterprises to implement DSM target responsibility assessment scheme"; In October 2012, the Ministry of Finance and the national development and Reform Commission initially selected Beijing, Jiangsu Suzhou, Hebei Tangshan and Guangdong Foshan as the first batch of pilot units; In July 2015, the national development and Reform Commission and the State Energy Administration issued the guidance on promoting the development of smart grid.

In 2003, more than 70% of the power shortage in China was alleviated by DSM's orderly power consumption measures. In Jiangsu Province, 450000 kW energy efficiency power plants have been built in three years, saving 2.9 billion kwh of electricity annually. In Hebei Province, 1% of the urban surcharges collected on behalf of the sales electricity price are used for the construction of demand side projects such as energy efficiency. From 2004 to 2006, the accumulated power saving is about 500 million kWh, and the peak load can be transferred to nearly 60000 kW during the peak period of power consumption. From 2007 to 2009, through the implementation of DSM, about 90-100 billion kWh of electricity was saved, more than 54 million tons of raw coal was saved, and about 900000 tons of sulfur dioxide emissions were reduced. More than 70% of the country's electricity shortage is solved by orderly electricity consumption measures, and the peak load of electricity consumption is about 16 million kW.

Shanghai launched China's first DR city pilot project in the summer of 2014. A total of 64 users participated in the pilot project, and their electricity consumption increased from 30% to 47%. At the same time, the peak period of electricity consumption is from 7:00 p.m. to 9:00 p.m., and then to the valley time after 10:00 p.m. Jiangsu Province successfully implemented the first provincial wide electricity DR on August 4, 2015, with an agreed load of 1.6274 million kilowatts and an actual load reduction of 1.6577 million kW, China Electric Power News reported. According to the document of the national development and Reform Commission (NDRC [2017] No. 1690), from 2012 to 2016, power grid enterprises actively took measures to promote their own electricity saving and social electricity saving, saving 55.3 billion kWh of electricity and 12.68 million kWh of electricity, respectively, exceeding the target task by 13.1 billion kWh and 3.59 million kWh.

2.1.4 New development of DSM in Japan

In the face of new changes in the electricity market, DR and VPP have emerged as important models of DSM. Traditional DR evolved from DSM, mainly based on price induction and administrative instructions, mainly including time-of-use tariffs, peak tariffs, and interruptible load tariffs. It can realize load reduction by issuing orders, but it is difficult to achieve rapid response. In the context of intelligent power grids, the new DR fully realizes automatic regulation. When the power supply is tight, the demand response signal to reduce the load is automatically sent to the user, and the power user automatically receives the signal, controls and adjusts the power consumption through the energy management system, and automatically reports the demand response result.

With the integration of large-scale renewable energy into the power grid and the rapid development of smart energy technology, new business models for the promotion and implementation of DR and VPP technologies have emerged in Japan in recent years. The rise of DR and VPP originated from five new changes in the Japanese power market environment.

The first is liberalization. In April 2016, Japan's electricity retail market has realized full liberalization, and diversified market players have joined the power market competition. As of March this year, more than 500 newly established power sales companies have been established, accounting for 13% of electricity sales, and the signing turnover rate of power companies has exceeded 16.2%. Moreover, power users can not only choose power sales companies independently, but can also directly participate in demand response and virtual power plant market transactions. The balance of power supply and demand no longer only depends on the “how much to use” on the power generation side, but instead through both supply and demand. Liberalization is the starting point for the reform of the Japanese electricity market.

The second is decarbonization. In order to achieve the goal of independent emission reduction targets of the Paris Agreement, Japan, on the one hand, started from the power supply side and vigorously developed renewable energy based on photovoltaic power generation to make up for the nuclear power gap and replace fossil energy. However, due to the shortcomings of renewable energy power generation itself, it still difficult to guarantee a stable supply of electricity; On the other hand, starting with DSM, in addition to relying on traditional energy-saving measures, deepening the potential of distributed energy on the user side has become a new path for Japan to achieve its decarbonization goal.

The third is decentralization. Compared with the traditional centralized power system that relies on large-scale thermal power, nuclear power, etc., Japan is building a new decentralized power system with small-scale distributed power sources such as photovoltaics and wind power as well as energy storage technology. The end users are not only consumers of electricity, but also "producers" of electricity.

The fourth is digitization. The deep integration of information technology and energy industry promotes the development of power digitalization. It can not only remotely control the power generation, energy storage and power consumption equipment at the user side, but also aggregate a large number of scattered small-scale power sources to form a strong power generation resource on the user side. The distribution system changes from the traditional one-way flow to the two-way flow that satisfies the balance of supply and demand.

The fifth is that the population is too small and sparse. It is predicted that the total population of Japan will drop by 30% by 2050 and half by 2100. The power demand is expected to decrease by about 10% in the next 10 years. The economy of scale in the power industry will be greatly challenged.

VPP is not only a distributed energy but also an innovative application of energy Internet. From the perspective of power supply, VPP uses the Internet and energy management technology to integrate and optimize the decentralized small-scale power supply owned by users for remote control and utilization, so as to supply power like a power plant; From the point of view of power consumption, through the aggregation control of user energy storage devices, the surplus power of renewable energy can be consumed and the balance of power supply and demand can be guaranteed. The scale and potential of distributed generation in Japan are huge, as shown in Table 2-4. It is estimated that by 2030, the installed capacity of distributed generation equipment in Japan will reach 25.91 million kW, equivalent to 25 million kW coal-fired power units; if 10% of energy storage equipment participates in power grid regulation, the scale will reach 13.2 million kW, equivalent to the regulation capacity of 26 million kw coal-fired power units.

Table 2-4 The scale and potential of distributed power in Japan (unit: 10,000 kW)

Classification	Equipment	Current	2020	2030
Power Equipment	Household photovoltaic	760	300	900
	Household micro fuel cell	10.5 (15 million units)	98 (140 million units)	371 (530 million units)
	Commercial Combined Heat and Power	1020	1120	1320
Storage Equipment	HEMS	9	2100	4700
	BEMS	400	1600	3100
	FEMS	180	530	1000
	EV/PHV	28 (11.4 million units)	450 (100 million units)	4400 (970 million units)

VPP and DR have overlaps and differences. VPP focuses on increasing supply, which will lead to reverse power flow, while DR focuses on reducing load and will not cause a reverse trend. Therefore, whether it will cause a reverse power flow in the power system is the main difference between the two. Japan defines VPP in a narrow sense as renewable energy power generation equipment and energy storage devices that are directly connected to the grid, while VPP in a broad sense also includes new DR on the user side, but traditional DR is not included.

In a broad sense, the distributed "power generation" involved in VPP mainly includes 1) power generation equipment, such as roof photovoltaic, fuel cell, micro cogeneration system, etc., while enterprises include self-provided generator, cogeneration system, renewable energy power generation equipment, etc.; 2) energy storage equipment, including household batteries, vehicle batteries, electronic water heaters, etc.; enterprises include fixed storage Battery, vehicle battery, refrigerated and frozen warehouse, heat pump, thermal storage air conditioner, electronic water heater, etc.; 3) energy saving equipment, including air conditioning and lighting equipment for families, and air conditioning, ventilation equipment, fan, compressor, cooler, water pump, etc. in enterprises. The promotion of VPP (DR) in Japan focuses on six major fields, including residential buildings, office buildings, factories, commercial facilities, public utilities and electric vehicles. The main form is "photovoltaic + energy storage". Table 2-5 lists the main business features of the VPP (DR) business model in Japan.

Table 2-5 Main business features of the VPP (DR) business model in Japan.

<table>
<tr><th>Beneficiary</th><th colspan="2">Main function</th><th>Basic summary</th></tr>
<tr><td rowspan="4">Transmission and distribution side</td><td rowspan="3">System stabilization</td><td>frequency modulation</td><td rowspan="3">Integrate distributed power generation, energy storage devices, load control and demand saving on the demand side, and provide various services for transmission and distribution enterprises through the real-time market.</td></tr>
<tr><td>Pressure regulation</td></tr>
<tr><td>Supply and demand balance</td></tr>
<tr><td colspan="2">Optimize investment</td><td>Using storage batteries to reduce the transformation and capacity increase of the system or substation.</td></tr>
<tr><td>Retail electrical side</td><td colspan="2">Electricity deployment
Make up for the cost difference caused by insufficient power</td><td>Load integrators and retailers will indirectly trade the allocated power through the negative watt market, futures market, and pre-hour market.</td></tr>
<tr><td rowspan="4">Demand side</td><td colspan="2">Reduce electricity bills</td><td>Peak shaving agreement, optimization of power purchase period.</td></tr>
<tr><td colspan="2">Maximum profitability of equipment utilization</td><td>Trade the surplus space of distributed power sources and energy storage devices through the negative watt market</td></tr>
<tr><td colspan="2">BCP</td><td>Distributed power supply and energy storage devices are used to ensure power supply in case of disasters.</td></tr>
<tr><td colspan="2">Incentive Protocol DR</td><td>Users participate in DR to get incentive rewards</td></tr>
<tr><td>Power generation side</td><td colspan="2">Reduce renewable energy curtailment</td><td>Utilize the deployment of energy storage devices to maximize the use of renewable energy.</td></tr>
</table>

Under the background of energy Internet, demand response (DR) and virtual power plants (VPP) have become the new favorites of the Japanese electricity market. Both can not only reduce system base load and peak load, and make up for the power gap caused by the massive shutdown of nuclear power, b but also increase the complementarity of multi-energy integration in the load side, which reduces the demand for thermal power peak shaving, and improves the utilization of renewable energy. At the same time, it promotes the optimization of the power grid according to the output characteristics of different types of power sources and drives the intelligent improvement of the grid. Therefore, DR and VPP have become a highlight of the current distributed energy Internet market innovation in Japan.

2.2 Review of DSM technology means

With the population growth, urbanization and climate change, the change of global energy structure, and the gradual advancement of electricity reform, the distributed energy system(DES) combined with renewable energy also ushers in unlimited development space. Power demand side management will gradually give consideration to energy-saving services, and energy trusteeship and energy efficiency trusteeship will become a new profit model. Energy transformation and energy system reform in developed countries have been in progress since the end of the 20th century. The social conditions and energy endowments of different countries are quite different, but all of them are developing towards a more market-oriented, clean and intelligent direction. To realize the comprehensive optimal allocation of multiple energy sources, and vigorously promote the construction of distributed generation integrating clean energy and renewable energy At the same time, through DSM, the user and Microgrid can be effectively integrated to play a positive role on the user side. The electricity consumption management mode will be changed from the planned economic mode to the market-oriented and consumers' comprehensive participation. In order to reduce the electricity demand in the peak period, realize the balance and optimal configuration of microgrid and the whole grid. The optimal DSM strategy can guarantee the short-term flexibility of the system by minimizing the generation and load curves. So as to minimize the cost of microgrid for system development and the electricity cost of users[1].The integration of DSM and the concept of energy hub, as the main component of future energy, plays an important role in improving power efficiency and reliability[2].

2.2.1 Changing the way users use electricity

The challenges facing the grid now and in the future include the integration of renewable energy, the increasing popularity of electric transport and aging infrastructure. Advances in household electricity management and energy efficiency programs may enable consumers to play an active role in demand side flexible providers, thus helping to balance the grid and contribute to safe and reliable development. At present, the more effective way to change the way of electricity consumption is direct load control. In terms of residential users' electricity consumption, it is the addition of distributed energy that enables users to become the supply side even on the user side, as well as various energy storage systems, such as hydrogen storage and electric vehicle storage.

The unrestricted growth of electricity demand due to the growth of world population, industrialization and insufficient power generation has intensified the pressure on the ability of public utilities to serve customers. Utility companies can adopt direct control methods, such as comprehensive control of user load during peak hours, to minimize the gap between supply and demand. Kalair[3] proposed a DSM scheme based on frequency and voltage relay to reduce the load of 11kv distribution feeders in peak hours without the aid of comprehensive load reduction.

DSM in DES is an effective method, which can balance the dynamic changes of electricity supply and demand on the consumption side[4], at the same time, the implementation of DES provides a new possibility to accommodate renewable energy. The realization of technology side means also depends on the acceptance of new technology by residents and the subsequent behavior changes. DES has become a promising integrated energy technology because of its energy efficiency and environmental benefits[5]。DES includes a variety of technologies, such as cogeneration system, gas-fired boiler, renewable energy system, electric heating device, electric storage and thermal storage. The demand for carbon in cities and communities has increased rapidly as climate change continues. DES can promote the development of low-carbon communities, and the reduction of costs and carbon dioxide emissions is obvious when cooperation is started under the guidance of the central energy management system[6].

The integration of variable renewable resources and decentralized energy technologies creates a demand for greater flexibility in energy demand. In order to fully deploy DSM method, it is necessary to systematically realize the synergy between interconnected energy systems[7]. Distributed generation system enables customers to invest in small power plants for their own consumption, which will relieve the transmission and distribution pressure of the power sector[8]. The main consumers with flexible load purchase electricity from wholesale market through strategic behavior, which not only reduces their own costs, but also reduces the spot price of electricity, which benefits themselves and benefits smaller consumers[9]. The use of cold and hot energy storage and off grid solar PV can also reduce and transfer the peak power demand and reduce the power consumption, which can save more electricity costs at the end of the year[10].

With the development of power market liberalization and the enhancement of people's awareness of environmental energy conservation, users can reduce energy consumption by switching between different energy operators and transferring energy consumption to off peak hours. In Japan, when consumers are free to choose different energy sources and suppliers, they are more likely to support environmental protection measures (such as generating electricity by themselves) to support the measures taken by power companies to enhance social environmental sustainability[11]. At the same time, the community power storage system is more flexible than the household power storage system, with lower investment and storage costs, which can provide promising potential for different participants in the energy system value chain[12]. Load characteristics and electricity price policy are important factors to determine the scale of energy storage. Ensuring the profitability of energy storage is the premise of its reasonable application in power system[13]. Direct energy storage can play a key role in the effective grid integration of renewable energy and the compensation of temporary power surplus and shortage. The performance of energy storage as thermal energy is better than that of direct energy storage[14].

2.2.2 Improvement of terminal electricity consumption efficiency

At present, in the process of the development of electric energy application at the user end, the overall development status is relatively good. However, in the process of specific application, there are still many problems. Problems such as: old power system network, lack of maintenance of power system, large difference of power application equipment, existing distribution network architecture problems, etc. The acceptance of DLC in equipment (such as heat pump, electric boiler, photovoltaic system, household battery) is higher than that of household appliances (such as dryer, washing machine, dishwasher, electric vehicle). It can be seen that there are significant differences in household interest in electricity price and acceptance of DLC[15].

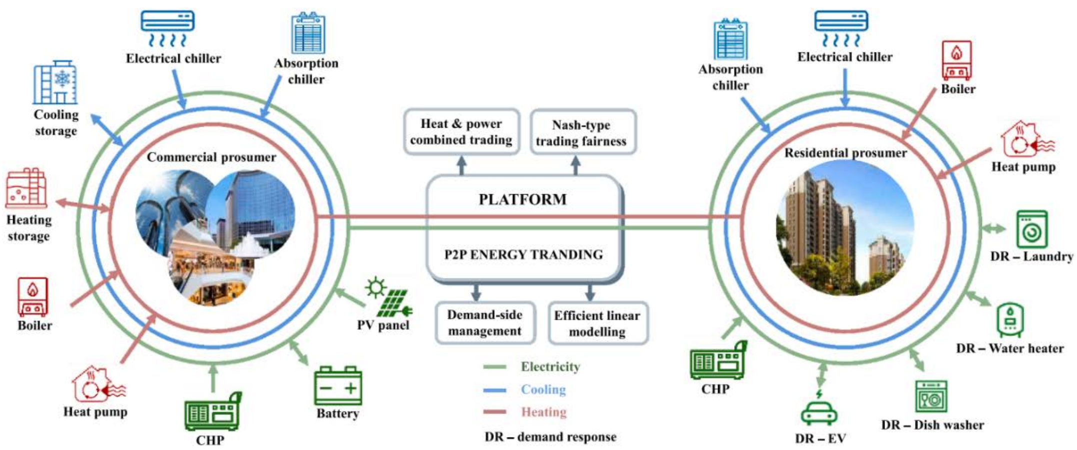
With the popularization of global electrification and the innovation of terminal electrical equipment, many countries have launched policies to improve the energy efficiency of terminal electricity. There are many studies on energy efficiency at the national level, mainly on trade openness, technological innovation[16], energy construction[17] and the structure of industrial energy intensity[18]. The main research methods include statistics and decomposition[19]. The analysis on the influencing factors of energy intensity mainly focuses on the national and regional scope[20], or specific industries and specific sectors [21; 22]. S Okajima[23] analyzed the relationship between the decreasing trend of energy intensity and the improvement of energy efficiency by using Fisher ideal index decomposition method. Huang[24] analyzed the influence of technical factors on energy intensity. PPetrović[25] explored the main factors affecting the energy intensity of the EU and compared different panel data from 1995 to 2015. O Gandhi [26] studied the change of energy intensity in Sao Paulo state from 1995 to 2012 through factor decomposition. And found that the impact of economic activities is gradually increasing. In China, with the pursuit of high-quality living standards, the types and quantity of household appliances are increasing, and household appliances are the main source of energy consumption. Consumers' willingness to refer to the energy efficiency label information has the greatest impact on their intention to purchase energy-saving household appliances, which indicates that the guidance role of energy efficiency labels is effective[27]. Compared with very poor households, poor and non poor households have lower electricity efficiency, while public sector employees have lower energy efficiency compared with the unemployed. The data show that the low efficiency of electrical appliances will lead to the waste of electric energy and aggravate the congestion of electricity consumption in peak period. The average efficiency score of the whole Ghana power consumption sample was 63.0%, and the average efficiency score of rural and urban households was 69.9% and 66.3%, respectively. This shows that Ghana has a great opportunity to implement energy-saving measures, especially in urban areas[28].

Yilmaz[29] estimated through the model that if household appliances were replaced by the highest energy efficiency labels available in the market, the power consumption of household appliances could be reduced by 21% and 38% respectively in the noon and nighttime peak hours. By replacing light bulbs with LEDs, the peak demand at night can be minimized, which is equivalent to a reduction of 18.8% in the total power consumption of household appliances, 14.2% in the total power consumption of residential buildings, and 5.0% in the total power consumption of the whole country. This means that by improving the electrical efficiency of household appliances, it is not necessary to transfer the appliances to off peak hours, but also to achieve the purpose of energy conservation and emission reduction in the morning and evening peak hours, and improve the comfort of users. Waseem[30] proposed an innovative home appliance scheduling (IHAS) framework based on the fusion of gray wolf and crow search optimization (GWCSO) algorithm. In the presence of real-time price signals (RTPS), the electricity consumption of household appliances can be reduced, and the electricity bill and peak-to-average ratio can be reduced.，It also maximizes the user comfort and improves the stability and reliability of the power grid.

2.3 Review of DSM economic means

At present, DSM mainly implements demand response (DR), which refers to all kinds of electricity prices, direct economic incentives and demand side bidding measures. The essence of these measures is to stimulate and encourage consumers to change their consumption behavior and electricity consumption, install and use efficient equipment, and reduce electricity consumption and demand. In order to ensure the power balance of the power grid, ensure the stable operation of the power grid, and promote the operation mechanism of the optimal operation of the power grid. The price of electricity is made by the supply side, which is a controlled economic means, and the user responds passively. Direct economic incentive and demand side bidding are incentive economic means. Demand side bidding has joined the competition, the users respond actively, and the users who actively use these measures make contribution to the social benefits, but also reduce their own production costs and even obtain some benefits. In essence, DR is a kind of market behavior to achieve the goal of optimal allocation of power resources through the active participation of electricity users in the balance between supply and demand. It is a realization form of demand side management characterized by user initiative. The balance of electricity supply and demand is facing many challenges, so it is necessary and urgent to estimate the power demand accurately[31].

As a result of numerous advances in information technology, all residential users around the world have the right to contribute to DR plans, using appropriate energy management systems to manage their electricity consumption and reduce related costs. In the era of decentralized energy, P2P energy transaction (as show in fugue.2-3) is realized between producers and producers, and between producers and consumers. The integrated demand response is the result of the improvement of power market competitiveness and one of the manifestations of power market liberalization.



Fugure.2-3 P2P energy trading diagram[32]

Integrated demand response is one of the important methods to promote renewable energy consumption and improve energy efficiency in integrated energy system. It makes multi energy users and demand side distributed energy stations become demand responsive resources, which can improve the utilization rate of renewable energy, realize the optimal allocation of resources, and save energy expenditure for users[33].

2.3.1 Demand side response （DR）based on price

Electricity price is a key factor affecting the interests of all participants in the power market, and it also plays an important role in the sustainable development of energy and environment. The way to achieve a win-win situation between power grid and buildings is still a challenge. Price based demand response is considered to be the most effective solution to match supply and demand in the housing sector. Based on the Nash equilibrium determined by Stackelberg game, Rui [34] developed a basic and enhanced interaction strategy between grid and buildings. The results show that the net profit of the grid is increased by 8% and the demand fluctuation is reduced by about 40% through the interactive strategy, which saves 2.5-8.3% of electricity bill for buildings. Staats [35] studied and analyzed the data of 42 households, 39 solar panel systems, 42 washing machines, 23 dryers and 24 dishwashers, and concluded that these three wet appliances have the potential to reduce peak value and photovoltaic self consumption.

In the implementation process of demand response, price change will lead to the change of electricity consumption by consumers, which will lead to the trend of the whole power load curve [36]. The ICT solution system researched by Azarova [37] realizes the communication between utility providers and home users, thus realizing the behavioral response of the family. Reducing peak demand is a key element of demand management plan for power grid stability. Many studies have shown that monetary incentive is the strongest incentive to change the electricity consumption behavior of residents [38, 39]. The price scheme should be easy to understand, the price change should be predictable [40], and the price measures will effectively restrain residential electricity consumption [41].

With the rapid development of smart grid, appropriate pricing scheme is very important to encourage customers to participate in power market operation. As a means of demand side management, price based demand response (PBDR) has promoted power market reform [42]. The most commonly used pbdr strategy is tou pricing and the combination of tou pricing and layered pricing. By analyzing the elasticity of electricity price demand, real-time pricing and step pricing have the function of peak load transfer. Real time pricing has higher overall benefits, such as peak shaving, delaying generation and network investment, and promoting the integration of renewable energy [43]. Residents' sensitivity to electricity price has a significant impact on cost saving.

Households with higher price sensitivity have stronger response trend to pbdr and have greater cost saving potential [44]. Lu [45] proposed a dynamic pricing demand response algorithm for energy management in hierarchical power markets. The algorithm can improve the profitability of service providers, reduce the energy cost of users, balance the energy supply and demand in the power market, and improve the reliability of the power system. It can be seen as a win-win strategy. These energy challenges cannot be fully addressed by pricing alone. It is important to implement a series of reforms aimed at reducing inefficient distribution, mismanagement, corruption, theft and other supply side infrastructure problems [46].

The use of dynamic pricing strategy has become a powerful DSM tool, which can optimize the energy consumption pattern of consumers and improve the overall efficiency of the energy market. Its main goal is to encourage consumers to participate in reducing peak load and obtain corresponding rewards as a reward [47]. The dynamic pricing scheme designed for micro grid demand response can effectively utilize renewable energy and main grid, so as to reduce greenhouse gas emissions, reduce power consumption and save energy [48]. Microgrid (MG), which is related to multiple distributed renewable energy generation, energy storage devices and random loads, has recently attracted extensive attention. Chen [49] proposed a multi-layer modeling framework for collaborative optimization of microgrid systems considering price based demand response procedures. The hierarchical results can emphasize both environmental and economic issues, thus providing a compromise power generation scheme and ensuring fair treatment of contradictions and conflicts of different interests. Yoon [50] proposed a price based Dr strategy considering the data-driven of HVAC system in the single-layer decision-making structure, which can effectively achieve its own goals through the operational flexibility of HVAC system, and ensure the stability of grid voltage and the thermal comfort of users. Multiple sources of energy procurement can include renewable energy, i.e. photovoltaic (PV) system and wind turbine (WT), as well as power market (PM), bilateral contract (BC) and distributed generation (DG) units. Pricing based on real-time pricing RTP and demand response plan as virtual power generation unit can increase the profits of retailers [51].

Renewable energy systems are also facing more and more congestion and reliability problems. Policy designers can set tariffs to encourage producers to improve their energy behavior. Price sensitive tariffs should aim to smooth the N-Demand curve of net demand and reduce demand for fossil fuel power generation. The price gap between the valley of net demand and peak demand needs to be greater to reward conscientious consumers and punish wasters. Therefore, this can encourage residents to take the initiative to adopt energy storage strategies, such as installing household batteries or purchasing electric vehicles [52].

2.3.2 Demand side response （DR）based on incentive

In order to meet the growing demand for electricity, many power markets use DSM strategy as an economic and effective alternative to the traditional supply side management strategy [53]. Incentive based demand response (IBDR) policy plays an important role in guiding residents' electricity consumption behavior. The households who responded to DR strategy saved 0.09 kwh of electricity in 1.5 hour response period than those who did not. In terms of family response, families with higher income and younger income, families with more air conditioning and small household appliances and high consumption of natural gas have higher participation in the policy [54]. Different flexible incentive rate strategies (IRS) can reduce the power load of different consumers, so as to reduce the operating cost of VPP and improve the practicability of consumers. It can also relieve the pressure of peak period, thus contributing to the stability of power grid [55]. The demand response algorithm of smart grid system with reinforcement learning and deep neural network enables service providers to purchase energy from their customers to balance energy fluctuations and improve grid reliability [56].

Paudyal [57] proposed an energy optimization method based on incentive to dispatch many household appliances in residential areas, and designed a new incentive compensation to compensate customers according to the degree of inconvenience. The results show that compared with all environment settings based on similar situations, this method can save 11.3% on average compared with the case based on TOU, and 6.2% can be saved compared with the case based on TOU. User flexibility reflects the user's reflection on economic quotation. Asadinejad [58] pointed out that the reward period of lighting and washing equipment is far lower than that of HVAC. However, due to the high proportion of HVAC in the total load, the flexibility is higher, and the total load reduction is the largest.

Demand response planning (DR) is expected to be one of the most effective alternatives to the traditional power supply and demand business because it does not require additional investment in power plants and equipment [59]. Aghamohamadi [60] uses an integrated response load model to illustrate load modifications due to price changes (related to PBDR programs) and incentives / penalties (related to IBDR programs) to maximize customer benefits while minimizing the total operating costs of EH systems.

The electric power demand brought by electric vehicle charging load may cause great burden to the power system. With the further scale promotion of electric vehicles, the impact on the power system may increase. At the same time, electric vehicle is also a highly flexible mobile energy storage unit, which has great potential in adjusting power load, improving power quality and absorbing renewable energy, and can also help to reduce the expansion demand of distribution network and even the whole network [61].

If no countermeasures are taken, the continuous growth of electric vehicles will reduce the reliability of power system. Orderly charging is an important means for electric vehicles to participate in power grid regulation in the form of controllable load, and it is an important means to avoid the negative impact of large-scale charging of electric vehicles on the power grid [62]. The orderly charging of electric vehicles can be regarded as a flexible demand response resource, which can play a role in peak shaving and valley filling to a certain extent [63]. Through the combination of smart grid and time of use electricity price and other means, electric vehicles are encouraged to choose or concentrate on charging in peak or low periods when the price is relatively low [64]. Charging facility operators and vehicle companies can act as load integrators, obtain financial subsidies by participating in demand response projects, and help reduce the life cycle cost of electric vehicles.

The large-scale popularization of electric vehicles will greatly increase the load requirements of buildings in highly urbanized cities. Compared with other interruptible loads in buildings, electric vehicles have higher charging flexibility [65]. Xun [66] uses a neural dynamics algorithm combining feedback neural network and inertial neural sub network to minimize the electricity charges of home users by adjusting the charging and discharging strategies of plug-in electric vehicles (PEV) according to real-time price (RTP) information. Specified energy management options can actually minimize energy costs and improve energy resilience after a power outage. Electric vehicles, on the other hand, can reduce energy costs by about 25% and provide loads in the event of a 7-hour blackout [67].

The peak demand for electric vehicles in the European Union from 2010 to 68 countries is helping to reduce the demand for electric vehicles in 2010. Vehicle to power interconnection (V2G) is a kind of distributed energy storage unit, which participates in the regulation of power grid in the form of charging and discharging. After the implementation of vehicle power interconnection, the charging and discharging of electric vehicles can realize peak shaving and valley filling, power frequency regulation, stabilizing the fluctuation of renewable energy power, and providing reactive power support for the power grid [69]. The participation of electric vehicles in V2G can almost eliminate the need to use high-cost generators to supply power to the system in peak hours, thus reducing the hourly cost of the system. The excessive production of renewable resources during low load hours can be used for charging electric vehicles to reduce emissions [70].

2.4 Review of power market research with demand side participation

2.4.1 Development stage of electricity market liberalization

Since the power system reform was formally carried out in the UK in 1989, more than 10000 kW users were allowed to choose power suppliers freely. A wave of power liberalization reform has been set off in the world. Over the past 30 years, different countries have developed various forms of electricity market models. According to the reform process of power system in different periods in Britain and the reform experience of other countries, the development of power market liberalization is divided into three stages, as shown in table 2-6.

Table 2-6 Main characteristics of different development stages and corresponding typical representative countries

Liberalization stages	Main features	Typical representative country
Primary	1. Break monopoly and introduce market competition; 2. Separation of power plant and power grid, bidding for access to the Internet; 3. Open power industry regulation (mainly open generation side and sales side).	China, India, UK (1989-2005)
Middle	1. All users, including families, can choose power suppliers freely, but there are few suppliers and the market power is obvious; 2. The electricity market mode is wholesale competition mode or retail competition mode; 3. The separation of power grid operation from power generation and power supply is realized in law and function.	Japan, Singapore, Portugal, Spain, UK (2005-2011)
High	1. There are many suppliers and the influence of market power is obviously eliminated through strong supervision mechanism; 2. The electricity market mode is retail competition mode.	Germany, USA (Texas, New York, etc.), UK (after 2011)

Japan and China realized the separation of power plant and power grid as early as 1990s and 2000s, and entered the bidding mode. However, the process of power market liberalization remained stagnant for a long time, and it was not until 2013-2015 that the reform process was pushed forward again. Among them, Japan fully opened the retail market in April 2020 and entered the intermediate stage of power market liberalization.

At present, there are seven major exchanges in the world. Among them, European Energy Exchange (EEX) is the largest power exchange with an average daily trading volume of 170000 MW. In 2014, the electricity trading through EEX reached an amazing 1952TWh. PJM exchange in the United States is currently responsible for the operation and management of power systems in 13 states and the District of Columbia. As a regional ISO, PJM is responsible for centralizing the largest and most complex power control area in the United States, which is in the third place in the world. PJM control area accounts for 8.7% (about 23 million people) of the total population of the United States, with load of 7.5%, installed capacity of 8% (about 58698MW), and transmission lines of more than 12800 km. There are two main ways for countries to introduce competition in power sales side: one is to liberalize electricity sales, keeping power grid enterprises continue to engage in electricity sales business, at the same time, introducing independent power sales entities to allow other enterprises to engage in electricity sales business; The second is to implement the separation of distribution and sale, that is, the separation of property rights between power sales business and distribution business. Enterprises with distribution assets are prohibited from engaging in electricity sales business, and other enterprises are allowed to engage in power sales business. Table 2-7 shows the basic situation of market development in typical countries.

Table 2-7 Basic situation of market development in typical countries

Countries	Restructuring mode of electric power industry	Sales side development process	Market structure of electricity sales
France	Introducing independent power generation company and independent power sales company while maintaining vertical integration company	From large users to small users. In 2000, more than 16GWh users (20%) were released; in 2003, more than 7GWh users (37%); in 2004, nonresident users (51%); and in 2007, all users were released.	EDF, a vertically integrated company of distribution, transmission, distribution and sales, accounted for 82.4%; Distribution and sales integration companies accounted for 4.3%; Independent power selling companies accounted for 13.3%.
Unit Kingdom	Power transmission is independent and power	From large users to small users. In 1990, more than	The six major companies of power

	generation, distribution and sales are gradually combined.	1000 kW users (30%); in 1994, more than 100 kW users (37%); in 1999, all users were released.	generation, distribution and sales integration accounted for 88%; In the household market, 44.9% of them are independent power sellers.
Japan	Introducing independent power generation company and independent power sales company while maintaining vertical integration company	From large users to small users. In 2000, we will release 20 kV and above 2000 kW users (30%); in 2004, we will release more than 500 kW users (40%); in 2005, we will release more than 50 kW users (68%); in 2016, all users were released.	The top ten integrated power companies accounted for 97%; 2.11% of the total electricity sales were independent.
New Zealand	The four links of power generation, transportation, distribution and sales were completely separated. The links of distribution and sale, as well as the links of distribution and sale, are gradually merged.	From small users to large users. In 1993, 20% of users below 50 MWh were released; in 1994, all users were released.	The users of the five integrated marketing companies account for 97% of the users in the market.

(Source: Zhejiang University, Guotai Junan Securities Research)

In the 1980s, the electric power system reform from the United States and Britain was the last one in all industries to introduce competition mechanism. The direction of British and American electric power system reform is privatization, marketization, deregulation and introduction of competition mechanism [71], which sets off a wave of global power market reform. The main factors affecting the competitiveness and efficiency of the power market include: local market power [72], market transparency [73], barriers to market entry [74], level of market risk management [75, 76], sufficient price signal [77] and market structure with appropriate incentives for investors [78]. The biggest benefit of electricity market reform will be to improve the efficiency of operation and investment, which is the result of establishing the economic framework of short-term operation and long-term investment decision-making. Market prices help to guide the level and composition of investment in utility scale generation, energy storage and demand side resources.

Before the implementation of electricity market-oriented reform, it is necessary to optimize the energy structure of power generation. The uneven distribution of energy resources in the United States leads to complex power structure. Its industrial electricity price is the highest among all sectors. Policy makers can adjust the reform plan of the whole power market according to the industrial input, so as to reduce the risk of power market reform [79]. To make the energy supply structure more reasonable, reduce the proportion of coal power generation, improve environmental protection and save resources. In terms of installed power generation capacity, China's power system is the largest and largest single source of greenhouse gas emissions in the world. In 2015, China began to reform the power industry, aiming to introduce market mechanism into wholesale pricing [80]. Electricity market reform could increase coal-fired power generation and complicate efforts to achieve air quality targets and reduce carbon dioxide emissions. By incorporating the environmental regulatory design of the power sector into the electricity market reform, policy makers can achieve the right balance between market-oriented and administrative methods to achieve emission reduction. In a liberalized electricity market, the coordination and financing of transmission infrastructure is a continuous challenge. The liberalization of electricity market in Mexico reflects the change of transmission planning responsibility A1 [81].

From 1990 to the mid-2000s, Europe successfully established a competitive wholesale market, privatizing decision-making and risk management around a new generation [82]. Since then, governments have become a major driver of investment levels and technology choices. The goal of European power market integration is to establish a unified energy market. Power circulation is not restricted by the power grid. Market coupling between interconnected power systems is realized, and market competitiveness is enhanced. Price convergence is a good indicator to measure the degree of integration of interconnected power markets [83]. The experience of Iberian integration shows that in order to promote competition and consumer choice, and to cope with domestic market forces, it is necessary to strengthen the integration with surrounding systems. Since the establishment of Iberian market in 2007, the integration has developed towards the direction of further convergence of spot prices [84]. Regional integration provides an opportunity for foreign power generation companies to compete with domestic power generation companies that may be dominant, thus reducing market power. The integration of renewable energy is a major aspect of European energy policy. In order to conduct more global analysis on the integration degree of interconnected power market, the influence of each region in the interconnected region can be extended to the larger regions of Europe [85]. At present, there are interdependence and cross-border externalities in the European power market, and national energy policies alone cannot solve the main problems such as renewable energy integration and supply security [86].

2.4.2 The influence of government policy and regulatory system on electricity market

An efficient regulatory system can reduce electricity prices and improve the welfare of end users [87]. The task of policy makers is to induce private agents to make decisions to maximize social welfare through their regulatory design [88]. However, when there is transmission network congestion, the higher regulatory capital cost may lead to lower merchant storage profit. In order to deal with market failure, effectively guide the behavior of game players and maximize the overall interests, it is necessary to strengthen the government's supervision on renewable energy power generation and transmission [89].

In the early 1990s, due to the improvement of the regulatory system, the joint operation of the power system made it easier for Spain's energy policy to transition to a new direction, and then to the European directive. After the market liberalization reform in Spain, the economic structure model has been improved and the influence of market forces has been reduced [90]. Among them, in order to prevent the chaos of the electricity market and improve the market efficiency, the Spanish government has implemented a series of intervention measures [91], which are mainly divided into structural intervention and regulatory intervention. The methods of merger and acquisition, including the way to enter the market, the way to reduce the barriers to entry into the market, and the ways to increase the company's ability to enter the market. Regulatory intervention mainly refers to regulatory reform, including the cost of transition to competition, which aims to provide compensation for regulatory transition, alleviate market incentives, auction key generator production capacity of virtual power auction, and universal promotion of forward contracts.

The regulation of retail electricity market is relatively intensive, including structural measures, contract restrictions, information provision rules, price supervision and market monitoring. In the Netherlands, regulation includes price regulation, that is, the regulator investigates all new retail prices before the market is launched to prevent excessive retail prices. Since more than a decade of liberalization, the Dutch electricity retail market has matured: the market has become transparent, and consumers can more easily switch from suppliers and products [92].

The result of the lack of competitiveness in the electricity market seems to be driven by the highly concentrated market, the high flexibility of competitive regulations, the background of high volatility and the particularity of auction design. Electricity demand itself is inelastic, so liberalization where there is no competition may lead to the deterioration of the uncompetitive equilibrium. The introduction of market regulation led to a 15% rise in electricity prices. However, if the regulatory framework is completely removed, the control of market operators on the centralized market will become very limited [93]. Research shows that corruption and regulatory quality have an obvious impact on residential electricity prices. Improving regulatory quality and reducing corruption will lead to the decline of residential electricity prices [94]. The incentive announcement suppresses the excessive return of suppliers' surplus, reduces the market power, and makes the residual distribution of participants more equitable [95].

2.4.3 The key point for demand side and power market: renewable energy

The uncertainty of renewable energy operation has brought great impact on the power grid, but the urgent demand for green energy system promotes the transformation of power system. DSM is one of the important means to improve the economic efficiency and consumption ratio of renewable energy [96]. At the same time, renewable energy is also one of the main driving forces to promote the process of power market liberalization [97].

Germany is one of the first countries to promote renewable energy development and power market liberalization. Germany's policy measures encourage the good integration of intermittent renewable power in the power system, because with the change of renewable power marketing mechanism, price volatility decreases [98]. From 2010 to 2017, the renewable energy in the German grid grew steadily, especially solar power [99]. However, the German power system has limited storage capacity at present, and feasible storage can provide stable effect for price and resist price fluctuation. On the way to improve the penetration of renewable energy in the power system, energy storage system is increasingly considered as the key flexible technology to support the operation of renewable energy [100,106]. In the case of high market share of renewable energy, EOM of pure energy market with strategic reserve can stimulate investment and ensure supply security [101].

The introduction of competition in the electricity market and the substantial growth of trading capacity, especially after renewable energy is one of the trading entities, will greatly complicate the task of maintaining the security and reliability of power arrangements [102]. Texas reduces the price of day ahead energy, day ahead energy and real-time energy through wind power development and demand side management. Texas also improves the efficiency of electricity trading by improving the forecasting accuracy of the Electric Reliability Commission Texas (ERCOT), thus narrowing the gap between RTM real-time market energy prices and dam energy prices. The price of auxiliary services (AS) increases with the dam energy price and AS procurement forecast, but decreases with the AS quotation forecast. The real-time market energy price of energy increases with the rise of dam energy price and the deviation of dam energy price [103]. In the process of power market liberalization, compared with the original power market monopoly, Japan's competitive advantage is not obvious [104]. Japan's wind power is still in its infancy, and the effectiveness of photovoltaic development in Japan cannot be compared with other advanced photovoltaic technology countries [105]. Nuclear energy is in a conservative political storage state, and coal fuel has a high economic efficiency. If we want to change the future low-carbon energy structure of Japan's open electricity market, we need to break the barriers of Japan's geographical location and cost, and re allocate resources.

The implementation of China's renewable energy portfolio standards (RPS) can, to a certain extent, improve the enthusiasm of power sales enterprises for renewable energy sales, so as to promote the development of renewable energy industry [107]. Improving renewable energy portfolio standards and carbon prices is conducive to the promotion of green power. The higher the portfolio standard and carbon price, the better the effect of power structure optimization [108]. Carbon tax is more cost-effective for reducing emissions, while production and investment tax credits are more cost-effective for increasing investment in variable renewable energy (VRE). Similarly, incentives to reduce electricity prices may require a separate revenue adequacy mechanism (e.g., capacity markets) than policies to increase electricity prices [109]. The power market design strategy will be affected by the policies that affect investment and operation decisions, and thus the market settlement price paid by consumers.

In the past decade, the cost of photovoltaic power generation in the United States has declined faster than that of value. Therefore, in 2017, the net benefit of utility scale photovoltaic power generation exceeded the cost of most modeling sites [110], and the optimal bidding considering different power market models can increase the financial benefits of photovoltaic power producers [111]. With the continuous development of power system and the increasing dependence on various renewable energy sources, technical solutions will become more and more important.

2.4.4 Demand side and electricity market

The structural spot characteristics of the electricity market determine the high price volatility [112]. Renewable energy and other economic and policy impacts have a certain impact on household electricity prices. However, the reduction of household electricity price is mainly related to the degree of power market-oriented reform, while the proportion of renewable energy in power generation is not statistically significant [113]. In addition to their own prices, the subsidy level obtained by consumers also has a significant impact on Residents' electricity demand. Social and economic variables at family level, such as income, education level, family size, electrical inventory and risk preference behavior, the availability of energy-saving technology and consumers' understanding of energy-saving technology are important factors for future energy-saving.

Since 2003, Singapore has taken a great step in deregulation of the electricity market. The establishment of the national electricity market (NEMS) in Singapore allows the issuance of electricity supply dispatching bidding on the wholesale side. Since the end of 2014, 80% of electricity consumers have been able to choose their own power retailers. With the development of power market liberalization, due to the change of oil price and power demand, the cumulative effect of fuel to gas power generation, the increase of installed capacity and the gradual intensification of retail competition, the electricity price has decreased by 9.11% [115]. With the completion of power market liberalization, the volatility and imbalance of spot price have decreased [116].

With the advent of deregulated electricity market, when the demand side stretches and bends with the changes of the new environment, the supply side dominates the market. By providing bidding strategies, the demand side assets are captured. In the electricity market environment based on power pool, the main problem is that the flexibility of the demand side is lower than that of the supply side. An appropriate strategy to expand the flexibility of the demand side is to use the demand side management plan [117]. Active load transfer of power demand releases a variety of benefits, which can improve the stability of the energy system, reduce the power cost, and save the capital of transmission and generation infrastructure [118]. Electricity price on grid is an effective means to achieve environmental goals and can be an essential part of a series of incentive measures needed to reduce carbon emissions from the construction sector [119]. In order to reduce the risk, retailers and large consumers can meet their demand from different sources such as bilateral market, self-produced and power pool. The motivation behind the liberalization of the retail industry in the power sector is that it is possible to transfer the benefits of deregulated markets to end users by providing lower prices and a wide range of contract quotations. Demand response is one of the means for small enterprises to enter the retail industry and manage their financial risks [104].

Demand response is an effective means to help maintain the balance of power supply and demand and promote energy conservation and emission reduction. Thanks to numerous advances in information technology, all residential consumers anywhere in the world have the right to participate in demand response planning, manage their electricity consumption, and use appropriate energy management systems to cut costs. According to the questionnaire, incentive based demand response (IBDR) projects can positively affect consumers to reduce electricity consumption [53]. If the incentive level is determined in advance by the consumer's agent (MO), the generator always responds to the incentive level and adjusts the strategy accordingly. When compared with oligopoly, incentive announcement can reduce the exercise of market power and restrain the excess return of suppliers.

2.5 New technology and research direction of demand side management

In 2019, the energy advanced research projects agency of the US Department of Energy announced that it would provide us $15 million to support the application of machine learning and artificial intelligence in energy technology and product design. With the development of power market-oriented reform, demand response and other DSM businesses are developing towards diversification and normalization. The new environment requires more and more reliability and accuracy of demand side management, so it is urgent to improve the technical support. The shortage of energy capital, the increasing cost of power generation, the reduction of load, the increasing demand of power supply and the concern for the environment aggravate people's concern about improving the overall performance of power system. As shown in Figure 2-4 is the demand side participates in the electricity market in the form of aggregators.

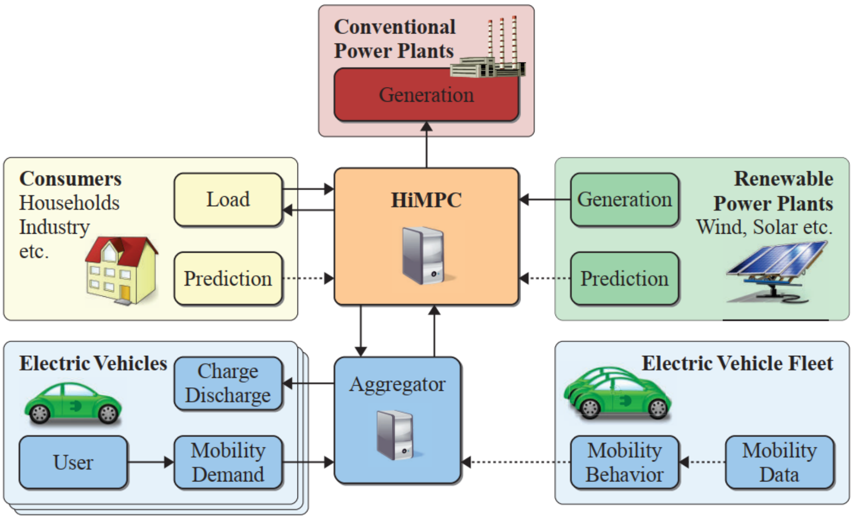


Fig. 2-4. Architecture of the energy management system

In DSM, customers are encouraged to use electricity in off peak hours, which has a very beneficial effect in the management and control of grid load. With the increase of the number of electric vehicles, Dr in DSM plays a more and more important role in power distribution system. In the case of frequency drop, automotive batteries interconnected with the grid can supply power to the grid instead of charging, thus avoiding the direct response of conventional power plants [120].

Due to technological advances, such as the popularity of smart appliances and electric vehicles, distributed renewable energy and improved Internet connectivity, electricity consumption patterns and willingness to participate in DSM programs may change in the future [121]. For example, hybrid biological heuristic computing intelligence (CI) technology can solve complex power system optimization problems [122]. Using deep learning technology to support natural language processing and computer vision services, we can establish an artificial intelligence platform framework for the power field [123]. AI model can solve the complex and nonlinear mode of original data to improve the accuracy of load forecasting [124]. Using the real-world scene generator to collect real power market information, combining data analysis with artificial intelligence to complete the modeling, we can get a result closer to the real situation [125].

2.5.1 The role of machine learning in power market and DSM

In recent years, with the increasing trust of demand response in improving the reliability of energy system, the demand for it is becoming higher and higher. With the high complexity of related tasks, the use of large-scale data and the frequent demand for near real-time decision-making, artificial intelligence (AI) and machine learning (ML) have become the key technologies to achieve demand response [126]. Machine learning technology has experienced decades of development. Recently, it has achieved great success in the fields of computer vision, speech recognition, natural language translation, chess and card games, automatic driving, art synthesis and so on, which is close to or even exceeds the human level. Through machine learning, we can analyze the rules of household electricity consumption, which appliances will be used in the relatively fixed period of time, and the household power load, so as to provide reference for some demand side schemes.

Artificial intelligence methods can be used to deal with a variety of challenges, including selecting the best consumer groups to respond, learning their attributes and preferences, dynamic pricing, scheduling and control of devices, learning how to motivate participants in Dr programs, and how to reward them. Electricity marketization is the general trend of global power system. The price of electricity is the core of this market. The fluctuation of electricity price affects the flow and distribution of various resources in the power market, which has a strong economic leverage. In the power market environment, accurate price forecasting is of great significance to all participants in the market. Although there are four common short-term electricity price forecasting methods: 1) time series method [127]; 2) neural network (ANN) prediction method [128, 129]; 3) prediction method based on wavelet theory [130]; 4) combination forecasting method [131, 132]. However, to a large extent, electricity price forecasting is a difficult task, because it depends on the weather, fuel, load and bidding strategy and other factors, which will have great fluctuations in electricity prices [133]. At the same time, the price volatility, high frequency, non-linear, mean regression and non-stationary and other complex characteristics of electricity price also cause great difficulties in forecasting.

At present, there are more and more research on the new methods of electricity price forecasting. Among these new methods, the most widely used is the electricity price forecasting based on machine learning. Machine learning is a way or subset of artificial intelligence, which emphasizes "learning" rather than computer programs. The accuracy of machine learning methods is generally better than that of statistical models [134]. Mori [135] proposed an EPSO method which uses Gaussian process of hierarchical Bayes estimation and Mahalanobis kernel as prediction engine and evolutionary computation to evaluate better super parameters in map estimation, and uses fuzzy c-means soft clustering as pre filtering technology. The adaptive deterministic and probabilistic interval forecasting system proposed by Yang [136] for multi-step forecasting of electricity price does not need to follow the assumption that the future value in the preprocessing will not affect the result of the model. It is a new forecasting technology with high practical value for management. Windler [137] used weighted nearest neighbor (WNN), TBATS method and deep feedforward neural network (DFNN) method to forecast the spot day ahead price, which improved the reliability of electricity price forecast. Based on the improvement of power market integration, sharifzadeh [138] developed a data-driven model through machine learning technology to achieve the purpose of quantifying the uncertainty in power grid and testing the predictability of its behavior.

With the rapid development of demand response technology, power system load data presents a large scale and complex structure of nonlinear characteristics. Load forecasting method based on deep learning and reinforcement learning, RL and efficient data processing platform is the current research focus [139]. Deep learning is a kind of technology to realize machine learning. It can accurately identify the complex external environment and make the optimal decision, which can meet the relevant requirements of demand response. Reinforcement learning also provides a smooth integration of prediction and optimization, because it maintains the belief in the current state and the probability of transition when taking different actions, and then makes decisions on which actions lead to the best results. Fan [140] combining machine learning method (empirical mode decomposition (EMD), support vector regression (SVR) model and particle swarm optimization (PSO) algorithm, thermal reaction kinetics theory and econometric model (ARGARCH model), a new hybrid forecasting model, namely EMD-SVR-PSO-Ar-GARCH model, is established, and an effective electricity forecasting model is obtained, which supports the feasibility of power generation Sustainable development. Zhang [141] developed a dynamic energy conversion and management strategy by using deep reinforcement learning. The algorithm shows that it can improve the profit of system operators and smooth the load curve of power grid in real time and effectively. An accurate power consumption forecasting model can be used to adjust the production and consumption patterns of electricity, and can also support the decision-making of energy policy, such as load unit combination, power plant operation safety and economic load dispatch.

Machine learning, deep learning and intensive learning can improve the accuracy and stability of electricity price forecasting. It can use the power side to formulate a reasonable power consumption plan and control the power consumption cost. At the same time, it can also play the role of peak shaving and valley filling. Accurate price forecasting is also conducive to the power generation party to accurately control the market trend, improve the system load rate, reduce the system operation cost, and ensure the stability of the system operation, To a certain extent, it can solve the problem of capacity shortage in some specific periods and a large amount of surplus in some periods.

2.5.2 The role of Internet and digital technology in power market and DSM

Deregulation of the power industry has led to significant changes in the energy market, and the era of energy Internet has come. There are usually two operation modes in power market, one is power pool market, the other is bilateral trading market. Bilateral transaction allows both sides of the transaction to price through free negotiation, which can better reflect the benefits of free competition, and the market is more transparent, which is the best market way. One of the urgent issues of energy transformation is how to integrate the consumer "producers" who start to produce electricity in the electricity market [142]. By supporting point-to-point transactions, blockchain technology transforms the way of "integrating market" into "becoming market" [143].

The problem with the traditional trading method is that the power companies often buy electricity at a low price and then sell it to customers at a high price, which leads to the inequality of energy trading. Through the blockchain technology, the P2P transaction of power can be realized, and the power producers and consumers can achieve a win-win situation [144]. The peer-to-peer (P2P) energy market allows private owners and consumer households of distributed energy resources (such as solar panels) to trade directly without intermediary [145]. This kind of project has been blooming all over the world, including PJM interconnection LLC (PJM), the largest power market operator in the United States, as well as the domestic energy blockchain laboratory, which are actively exploring. Compared with the traditional power trading mode, P2P power trading is still in development. Research shows that P2P market may bring new vitality to B2C power business model, and it is most likely to consider more consumers' preferences and interests [146]. Hackbarth [147] research shows that household users in Germany are generally open to P2P Power Trading (74.5% of respondents are neutral or positive), while 11% of respondents say that they are eager to participate in such an energy community in the next two years. P2P power trading can be effectively used as a potential solution to promote and manage the surge of producers in the future distribution system [148]. The network physical system based on blockchain can realize the interaction between different participants in microgrid (as shown in Fig. 2-5). Smart contracts guaranteed by blockchain technology can create efficient and highly trusted trading systems [149].

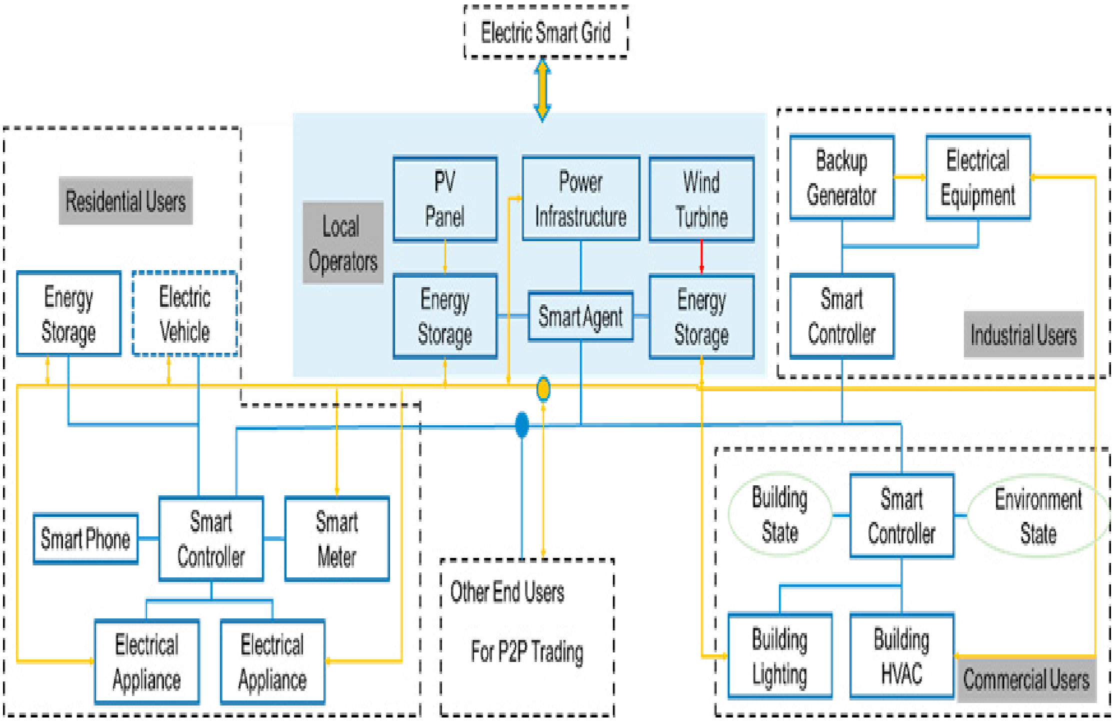


Fig 2-5 Blockchain based cyber-physical system to enable interaction between different actors in a micro-grid. [150]

In recent years, the smart grid (SG) system has been faced with various challenges, such as the growing energy demand, the huge growth of renewable energy system (RES) with distributed energy generation (EG), and the extensive adaptation of Internet of things (IOT) equipment [151]. The smart grid architecture based on the combination of blockchain and Internet of things is shown in Figure 2-6, zd25 [152]. Blockchain technology helps to enhance the sustainability of microgrid by rapidly balancing the supply and demand relationship in the grid [153]. Sustainable microgrid based on blockchain technology can increase profit margin and consumer satisfaction by 1.68% and 2.61% respectively, and reduce environmental impact by 0.97%. Cognitive Internet of things (CIoT) is regarded as the current Internet of things, which integrates cognitive and collaborative mechanisms to improve performance and achieve intelligence. The quality of information coverage (QIC) algorithm proposed by Liu [154] can improve the accuracy of data samples, thus ensuring the quality of intelligent incentive control mechanism.

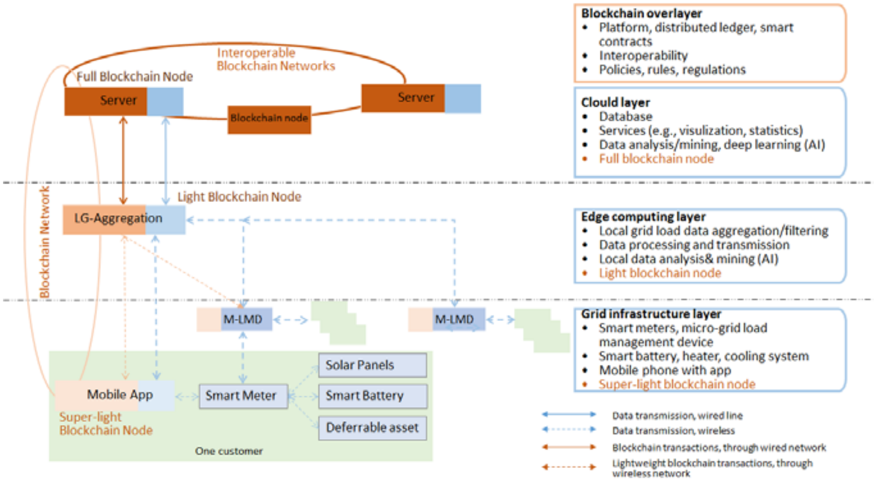


Fig.2-6. Structure framework of blockchain technology in smart grid based on Internet of things

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Chapter 3

TECHNICAL SIDE EQUIPMENT MODELING AND ECONOMIC SIDE THEORETICAL DERIVATION

CHAPTER THREE: TECHNICAL SIDE EQUIPMENT MODELING AND ECONOMIC SIDE THEORETICAL DERIVATION

3.1 Movement

Energy conservation and emission reduction has always been the core of global energy system. Although DSM has been promoted worldwide since 1980s, different countries have shown different development states and speeds. With the development of renewable energy and other new energy utilization methods in recent 20 years, demand side management (DSM) is playing a more and more important role in the whole energy system. At the same time, the new policies, new technologies and new ideas also make the realization of DSM more and more diversified. Although different countries have different policies and development plans for DSM, similar parts can still be extracted, such as equipment energy efficiency improvement, electricity price regulation and construction of distributed energy. Therefore, taking Japan as an example, this paper studies from the above three aspects, combined with the three different levels of country, large region and small region.

Due to the earlier development of DSM in Japan, the accumulated large amount of relevant data and a long enough time span are also helpful to obtain obvious and instructive conclusions. At the same time, Japan's DSM policy has always been conservative towards the opening of the electricity market. Only after the nuclear leakage event in 2011 led to the nationwide outage of nuclear energy and the sharp increase of power supply pressure in the power grid, did Japan gradually open up the electricity retail market. Therefore, the research on Japan includes the analysis of the effect of long-term implementation of policies and the summary of the guiding significance, as well as the analysis of the effect of the new electricity market opening stage, as well as the preview and adaptability research of DSM mode under the dual effects of future policies and electricity market. It is hoped that it can provide practical reference for the development of other countries in terms of technology side development, and Japan's future planning theory in terms of economic development.

3.2 Demand side basic model

In the electric power production, the power demand of users affects the formulation of power production plan. The power demand of consumers depends on three factors: (a) the number of electrical equipment; (b) the power of electrical equipment; (c) the use of electrical equipment. And item (c) is determined by user behavior, which is undoubtedly the most complex and unpredictable factor. At present, there is not a set of effective theory and method to study the conversion model between user behavior and power demand. In actual life, from the data of electricity demand generated by known user behavior, it can be seen that due to the difference of user behavior and time, there are differences in the level of electricity demand among different users and at different times. These differences are the complexity of this task. Therefore, this paper proposes a power demand model about the relationship between user behavior and electricity consumption.

3.2.1 User behavior description

User refers to a family consisting of S members, or a company owning S production units (workshops), and its user behavior refers to the set of activities engaged by S members in the user:

$$\{x_1(t), x_2(t), \cdots, x_s(t)\} \tag{3.1}$$

where, $x_j(t) \in X$ is the activity of the j th person at time t, X is the activity set.

The activity of each member of the user has time attribute, which can be deterministic or random uncertain. For this kind of uncertainty, we can use Markov chain to describe it. Markov chain is a stochastic process with discrete time and state [1]. For the activity of individual its transition probability can be described by function $p_j : X \times X \mapsto [0,1]$ where $p_j(x_j(t), x_j(t+1))$ is the probability of individual j 's transition from activity at time t to activity $x_j(t)$ at time $t+1$ activity $x_j(t+1)$ [2], which satisfies the following conditions:

$$\sum_{x_j(t+1)\in X} p_j(x_j(t), x_j(t+1)) = 1 \tag{3.2}$$

3.2.2 User demand model

Users are engaged in a variety of activities to use one or more kinds of electrical equipment; different activities use electrical appliances in different ways. We can use σ to describe the load rate of different activities and different appliances to express the mode of electricity consumption. Assuming that $\sigma : X \times E \mapsto [0,1]$ is the load mapping of the active appliance, then $\sigma(x,e)$ represents the load rate of the appliance e under activity x, while $\sigma(x,e)p_e$ represents the actual load of the appliance e under activity x, where p_e is the rated load of the appliance e.

Based on the above assumptions, under the deterministic user behavior $\{x_1(t), x_2(t), \cdots, x_s(t)\}$, the load rate $\delta(t,e)$ of electrical appliance e at time t and the actual user load $p(t)$ are respectively:

$$\delta(t,e) = \sum_{j=1}^{s} {}_{\oplus}\, \sigma(x_j(t), e) \tag{3.3}$$

$$p(t) = \sum_{e \in E} \delta(t,e) p_e = \sum_{e \in E} \sum_{j=1}^{s} {}_{\oplus}\, \sigma(x_j(t), e) p_e \tag{3.4}$$

where, $\sum_{j=1}^{s} {}_{\oplus}$ is a shared operation, which may take the maximum value, the minimum value, or the general sum. That is, if the actual power of electrical appliances is adjustable, and the maximum value is taken in general cases and the minimum value is taken in special cases under the condition of multiple people sharing the power; if the actual power of electrical appliances is fixed and is used by many people independently, the sum is generally obtained.

3.2.3 Problems existing in consumers' living electricity consumption

Power load classification reflects the power consumption situation and change law of various departments of the national economy. It is one of the indicators to measure the development level and trend of electrification. It is often used to analyze the relationship between economic growth and power production growth, social product growth and power consumption growth, and is also the basis for power load forecasting and power distribution. Load types of power system can be generally divided into rural power consumption, urban civil load, commercial load, industrial load and other loads. Different types of load have different characteristics. In recent years, with the rapid growth of electricity consumption, many problems have been exposed under the background of shortage of power resources and energy conservation and environmental protection, mainly in several aspects.

(1) Electricity price cannot compensate the cost and cross subsidy is serious.

Residential electricity is low-voltage power, which has the characteristics of small consumption, scattered user locations, large investment in technology and equipment hardware, higher energy loss and transmission cost than industrial power consumption, and the shared supply cost is also higher. According to the rationality of price, users should charge a higher price, while the residential electricity price in China is only one-half of the industrial power price. In recent years, the residential electricity price has been stable and unchanged. The residential electricity price deviates from the power supply cost, and the loss is cross subsidized by industrial power. According to the actual situation, in developed countries, the electricity price of residents is high, and that of industrial users is low. However, in most areas of China, the price of industrial electricity is higher than that of civil power.

（2）Invalid distribution of social welfare

The single electricity price structure makes the power supply cost of users unable to reflect the difference, the burden of users is unequal, the families with good economic conditions and more electricity use have more subsidies, and the families with poor economic conditions and less electricity use have less subsidies. This leads to the phenomenon that the rich take a free ride to the poor, and social welfare cannot effectively tilt to low-income groups, but it takes care of the high-income groups, which forms an unreasonable phenomenon Unfair insinuation. From the perspective of classified management of electricity price, many developed countries implement various sales electricity prices, while China's sales price is relatively single.

（3） Price cannot regulate the relationship between supply and demand, resulting in inefficient use of power energy

The electricity price of residents has not been adjusted in recent 20 years, and there is no price difference between peak period and low period. High power air conditioner and other electrical appliances in residents' homes are turned on all day long, which can not effectively guide residents to form the habit of reasonable power consumption and peak shaving and valley filling. Due to the priority of protecting residential electricity consumption and limiting industrial and commercial power consumption in both peak and low power consumption periods, it is inevitable that large-scale power restriction for industrial users occurs every year, and the power resources cannot be optimized.

（4）Reliability price is an important problem in power market.

Different users have different requirements for power services. Some users are willing to pay higher electricity prices to get high reliability power services. Some users are willing to sacrifice high reliability and get low price rewards. However, this kind of reliability price is not reflected in the day ahead price system. The time-sharing characteristics and load rate of users should be taken as the basis of pricing, but the current pricing system is not considered enough.

The main reasons for the above problems are as follows:

（1）The level of residential electricity price is low, and the price gap between high-voltage power supply and low-voltage power supply is too small.

Residents use the same electricity price, and the part of the power company's loss is subsidized by the higher electricity price of the industrial company's users. This compensation mechanism leads to the welfare electricity price for all residents in a society, which increases the burden of industry and commerce. The compensation mechanism needs to be improved and only the low-income groups who need to subsidize less electricity are subsidized. It is because the low-voltage power supply price is low, and the high-voltage power supply price is high. In order to reduce the power supply cost and increase the profit level, power supply companies compete for high-voltage power supply, and there are more and more intermediate links in the sale of electricity, which makes the power sales not smooth. If the original price difference of high and low voltage power supply is more reasonable, the low-voltage power supply of the power supply company can be profitable, perhaps the rural power network transformation and construction will not be so arduous.

（2） The price structure is unreasonable.

At present, the single linear electricity price structure of residential electricity consumption cannot reflect the difference of power consumption, stable users and large power consumption, seasonal unstable users' different requirements for power grid equipment structure, which leads to the difference of power supply cost of users and unequal burden of users. At the same time, the linear electricity price structure leads to the unreasonable distribution of social welfare with more power consumption and less subsidies.

3.2.4 Main influencing factors of electricity load of users

In the intelligent residence, the power load includes household appliances load, lighting load and household intelligent facilities load, which is the decisive factor of the user's electricity load. The most important indicator reflecting the load is the popularization rate of all kinds of household appliances (that is, the average number of household appliances owned by every 100 households). It is the direct reflection of the living standard of residents. Its basic value determines the current residents' electricity consumption, and its development speed determines the future electricity consumption. The factors affecting the power consumption load of users mainly consist of the following aspects.

（1） National and regional economic development and the level of residents' income.

The income gap between China's urban and rural areas and between the urban and rural residents in China is more significant. In areas with high economic development level in China, the power load of users will show a trend of rapid growth; regions or families with different economic income have great differences in the demand for various household appliances and electricity load, and the ability to bear electricity charges, which is mainly reflected in: the higher the economic income, the higher the living standard of residents, the higher the degree of electrification, and the increase of peak valley difference of the system. （2） The influence of regional climate conditions.

China has a vast territory, and the climate is very different. The difference of load characteristics between regions is largely caused by the difference of climate conditions among different regions. For example, the load characteristics of the South and the north are different. The summer peak cooling load in the south is greater than that in the north, and the heating load in winter is also greater than that in the north. Generally, the change of climate conditions has a great impact on the monthly load. For example, the average temperature is higher than the summer months of the same period, and the peak valley difference is large. Moreover, with the continuous improvement of residents' living standards, high-power electrical appliances such as dual-purpose air-conditioning, instant electric water heater, electric stove, electric heating, washing machine with drying, and household electric hot water system are entering the family, which will greatly increase the power load of residents.

（3） The influence of residents' living standard and consumption concept change.

With the improvement of the income level of urban and rural residents and the improvement of living conditions, the consumption concept of residents has gradually changed from simple and economical to comfortable and luxurious. It can be predicted that the home appliance ownership rate of urban and rural residents, especially urban residents, will grow rapidly. Air conditioning, electric cookers, electric heaters and electric water heaters are all high-power, high-power household appliances. At the same time, the increase of the number and area of rooms has a greater impact on the ownership and load of air-conditioning facilities. The above will directly lead to a substantial increase in residential electricity consumption, and will lead to the increase of peak valley difference.

Whether household appliances are shared appliances can be divided into three steps. The first level of electrical appliances are shared appliances, such as TV sets, refrigerators, washing machines, etc., which are called class III household appliances; The electrical appliances in the second stage are non-shareable appliances, such as computers, audio, electric water heaters, etc., which are called class II household appliances; The third level of electrical appliances can be shared or used alone, such as lighting, etc., which is called class I household appliances. The corresponding categories of household appliances are shown in Table 3.1.

Table 3.1 The the development law of household appliances popularization rate.

Name of household appliances	Reference capacity /kw	Category	Remarks
TV sets	0.1-0.2	III	Cultural and entertainment equipment
Audio	0.2-0.3	II	
DVD Player	0.15	III	
Video recorder	0.06	III	
Computer	0.5	II	
Rice cooker	0.8	III	Kitchen equipment
Electric oven	1.0	III	
Electric kettle	1.5	III	
Refrigerator	0.1-0.2	III	
Smoke lampblack machine	0.2	III	
Microwave Oven	1.0	III	
Sterilizer	0.6	III	
Electric dishwasher	1.0	III	
Electric cooker	1.5	III	
Washing machine	2.0	III	Sanitary bath equipment
Washing machine with drying function	3.5	III	
Vacuum cleaner	0.8	II	
Electric iron	1.0	II	
Electric water heater	2.0-3.0	II	
Instant electric water heater	3.5-4.5	II	
air conditioning equipment	1.5-4.5	III	Air conditioning and heating equipment
Electric heater	1.0-2.0	III	
Electric fan, ventilator	0.1	I	
Lighting facilities	0.2-0.8	I	Other
Home automation facilities	0.2-0.5	I	

（4） The influence of demand side management .

Power demand side management (DSM) is a kind of man-made influence factor. The purpose of DSM is to realize the economy of power supply and improve the reliability of power supply. The main technical measures adopted in DSM include peak shaving, valley filling, peak shifting, strategic power saving, strategic load growth and flexible load increasing. Its purpose is to reduce the power demand of users in the peak load period, so that the power demand is growing and the load is relatively stable. Effective power demand side management, such as guiding large users to realize peak load shifting by adjusting variable operation process and power consumption plan, providing power saving and energy-saving technical guidance for power users, helping them use electricity reasonably and realizing the purpose of strategic power saving and peak shaving and valley filling. The price mechanism is used to increase the proportion of new electricity using low valley energy, so as to ensure the power demand of users and realize the purpose of load valley filling and flexible operation. In addition, if necessary, the blackout price system (interruptible load price) should be implemented for high power consumption users or large power consumers, that is, in the period of power supply shortage, the amount of electricity load and electricity consumption that users can reduce can be given certain financial subsidies, so as to achieve the purpose of reducing peak power consumption, improving the reliability of power supply and consumption, avoiding losses and improving the efficiency of power supply and consumption.

3.3 Modeling and analysis of typical energy consumption and energy supply equipment

3.3.1 Characteristic analysis of typical energy consuming equipment

The user's electricity load mainly includes the electric load of household electric lamps, TV sets, air conditioners, refrigerators, heating, microwave ovens and other electrical equipment. The characteristics of electricity load are closely related to the regularity of daily life and work, especially in the aspect of fluctuation with time. With the rapid development of economy and the steady improvement of living standards, the degree of electrification of people's life is also increasing day by day, so the proportion of electricity load of users in the whole power load is gradually increasing. In summer and winter, the cooling load and heating load of civil air conditioning account for a large proportion of the power load of users, which has become an important factor affecting the power load, and is also one of the important reasons for power system switching off and limiting in peak season. Generally speaking, the main characteristics of the user's electricity load are: it has regular annual growth, is affected by weather such as temperature and humidity, and obvious seasonal fluctuation, and its seasonal change can directly affect the seasonal change of peak load of the system.

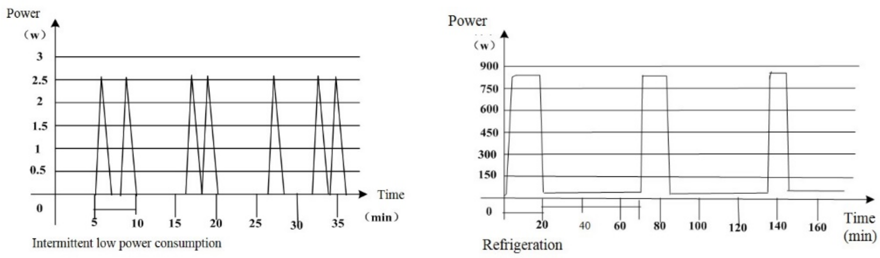
At present, the power consumption of urban residents has changed from lighting to refrigerator and air conditioning, which has a significant impact on the planning and design of power grid and the safe and economic operation. Due to the different use mode of each electrical appliance, the load rate of each appliance is different in the same service time. According to whether the appliance is a shared appliance, the following typical electrical loads are analyzed.

（1） Air conditioner

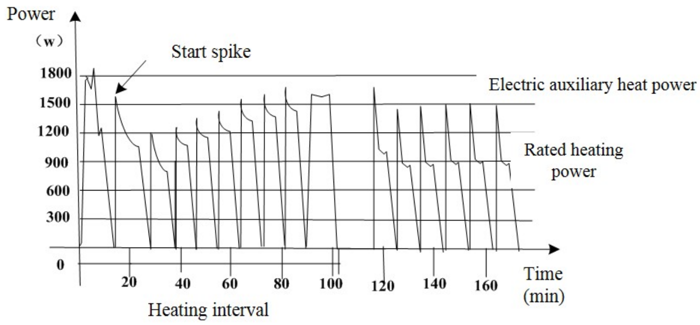
In recent years, air conditioning load has become one of the main factors that affect the growth of electricity load. According to statistics, the total sales volume of 2012 fiscal year was 64.9723 million units, with a year-on-year increase of 3.64%. Among them, the contribution rate of variable frequency air conditioner has exceeded that of fixed frequency air conditioner, with a market share of 52.54%, and the sales volume and sales volume of variable frequency air conditioner have increased by 8.3% and 16.2% respectively [3]. With the increase of air conditioning power load, the load is increasing in peak period, and the peak valley difference of power is further enlarged, which causes great pressure on the power grid.

With the development of economy and the improvement of people's living standards, it can be predicted that the air conditioning load in China will show a trend of rapid growth, and the impact on the economic operation of power grid and the balance of power supply and demand will be more and more serious. Therefore, it is necessary to master the total amount and characteristics of regional air conditioning load, understand the variation law of air conditioning load, formulate effective measures to control the growth of air conditioning load in peak hours, improve the load characteristics of power grid and improve the economy of power grid operation.

At present, the air conditioning on the market is generally divided into refrigeration, heating, dehumidification, ventilation and other modes, the more commonly used are refrigeration and heating. As shown in Figure 3-1, where (a) is the power consumption of the air conditioner during standby.



(a) Power consumption of air conditioner in standby state (b) Power consumption of air conditioning refrigeration mode



(c) Power consumption of air conditioning heating mode

Figure. 3-1 Common modes of air conditioning

The load rate of the air conditioner is directly related to the indoor temperature. Because different users have different requirements for the ambient temperature, the room temperature is finally reflected to the user, so the user determines the load rate of the air conditioner. Under the condition of multiple users, the air conditioner belongs to shared appliances, so the load rate is $\delta(t,e)=\sum_{j=1}^{s}\oplus\sigma(x_j(t),e_{空})$, in which $\sum_{j=1}^{s}\oplus$ takes the maximum value.

（2）Lighting

From the time characteristics of lighting load in recent years, residential and commercial lighting power consumption is becoming a major factor causing the peak load of power grid. China's State

Energy Administration released electricity consumption figures for 2012, which showed that the life of urban and rural residents last year was 621.9 billion kWh. Among them, 25.4% and 38.2% of urban and township residents' lighting power consumption accounted for their respective household total power consumption.

The lighting load can be described as:

$$p(t)=\begin{cases} p_{\min}\dfrac{L(t)}{L_{\lim}}+p_{\max}(1-\dfrac{L(t)}{L_{\lim}}) & L\le L_{\lim} \\ p_{\min} & L>L_{\lim} \end{cases} \tag{3.5}$$

where, $L(t)$ is the light intensity at time t, $L_{\lim}$ is the set light intensity;

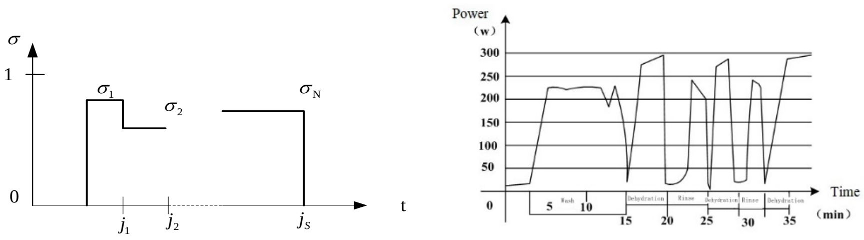
At present, China's lighting power consumption accounts for about 12% of the total social electricity consumption, so the power load generated by indoor lighting accounts for a large part of the users, and the demand for light intensity of each person is different. Therefore, when lighting equipment is shared, selecting the highest lighting demand will cause discomfort to users, so the lowest lighting demand is selected, that is, $\sum_{j=1}^{s}\oplus$ takes the minimum value; When the lighting is not shared, $\sum_{j=1}^{s}\oplus$ is the general sum.

(3) Kitchen

Today, there are many kinds of kitchen appliances, which can be divided into three categories from series, namely, food cooking appliances, food processing appliances, and food storage and cleaning appliances. First, the cooking electrical appliances mainly use electricity as the energy and convert the electric energy into the heat energy needed for cooking food. For example: automatic electric rice cooker, electric frying pan, electric frying pan, microwave oven, induction cooker, etc. Second, there are many kinds of food and beverage processing appliances, mainly including multi-purpose food processing machine, juicer, blender, ice cream machine, food waste processor, electric coffee grinder, drinking machine, etc. The third is the storage and cleaning electrical appliances, including: electronic disinfection cabinet, dishwasher, vacuum fresh-keeping machine, oil fume removal machine, and refrigerators, refrigerators, freezers, etc. In order to facilitate the establishment of the model, it is assumed that the load rate of all electrical appliances is constant in the cooking behavior, which is collectively called cooking utensils $e_{炊}$, In the load rate, $\sum_{j=1}^{s}\oplus$ is the general sum.

（4）Washing machine

Washing machine is a common household electrical appliance, most of the current washing machines are fully automatic washing machines, which are generally divided into washing dehydration rinsing dehydration, rinsing dehydration and other selection modes. According to the washing procedure, washing and dehydration are carried out alternately, and the power of each stage is different. The power of washing machine is generated after the behavior of using electric appliances is completed. The load rate can be divided into N levels according to the N selection modes of the appliance itself（σ_1, $\sigma_2 \cdots \sigma_N$）, As shown in Figure 3--2 (a). Figure 3-2 (b) shows the power curve of the washing machine in a certain mode of automatic gear.



(a) Load rate of washing machine （b）Power curve of washing machine in certain mode

Figure 3-2 Load rate of washing machine and power curve of a certain mode.

3.3.2 Analysis on the effect of typical energy consumption equipment in user load

The power load of users has strong periodicity and randomness. The change of power load mainly depends on the regularity of people's production and life, and is affected by many related factors such as economy, time, climate and so on. The periodicity of power system load refers to the repeatability of load variation in a certain period of time. It is an inherent law of power system load, which generally includes annual periodicity, weekly periodicity and daily periodicity. According to the research content of this chapter, we will focus on its weekly and daily periodicity.

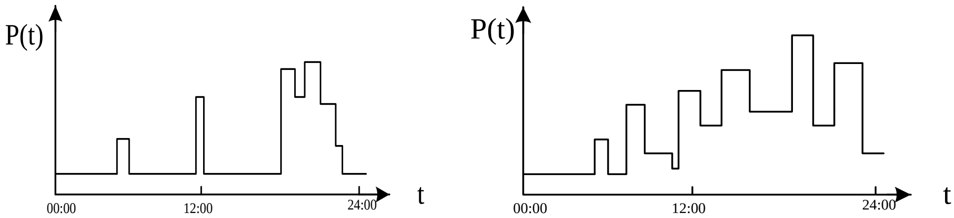
The weekly periodicity of power load change mainly refers to the regularity of power load change within a week. The main reason is that people's daily production and life are mainly planned and arranged on a weekly basis. During the working day, the electricity load of users is relatively small. On the other hand, during weekends or holidays, the power load of users increases greatly.

The periodic change of power load is not a simple repetition of the number of the previous cycle. In different periods, the value of power load is different, and the magnitude of the value change has certain randomness, which reflects the influence of internal and external factors on the power load. In addition, the characteristics of power production determine the continuity of power load, that is, under normal conditions, the load curve between any two adjacent points is continuous change, there is no singularity. Due to the periodic characteristics of power load changes, then in a certain period of time, the load changes are similar, and the amplitude of power load at the same time of day is approximate, that is, the values are close to each other. Therefore, it is necessary to observe the fluctuation of load value at the same time in a continuous period of time.

To sum up, the total power $p(t)$ of users is obtained as follows:

$$p(t)=\sum_{e\in E}\delta(t,e)p_e=\sum_{e\in E}\sum_{j=1}^{s}\oplus\sigma(x_j(t),e)p_e \tag{3.5}$$

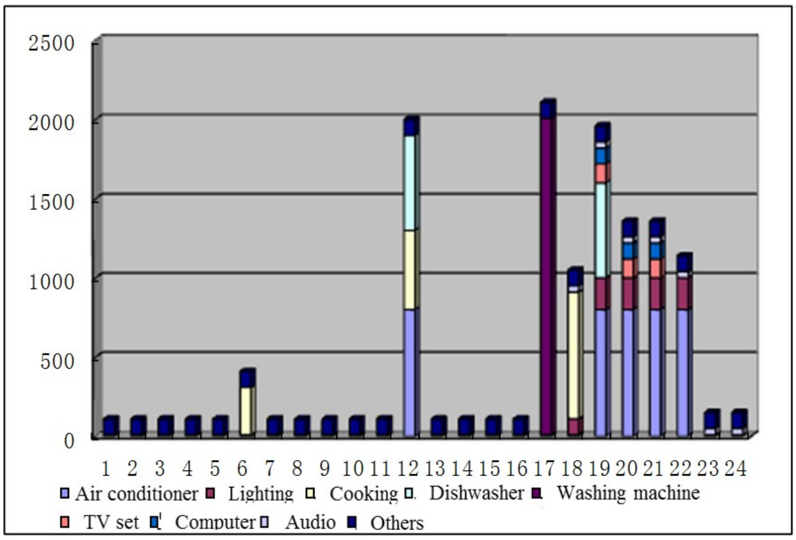
Through the investigation and analysis of a residential area in Dadong District of Liaoning Province, the behavior data and power consumption data of users in each time period are obtained, and then the statistical analysis of power consumption data is carried out, and the results are shown in Figure 3-3. Figure 3-3 shows the power consumption statistics of users on weekdays and weekends in summer.



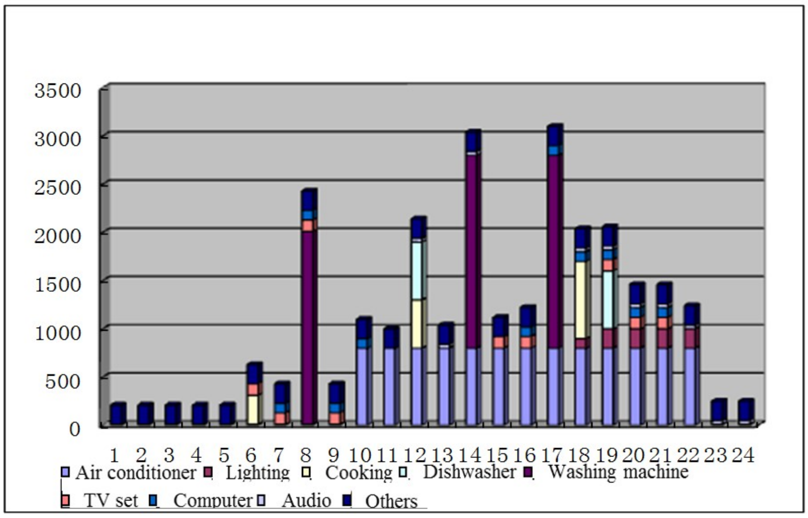
(a) Weekdays (b)Weekends

Figure 3-3 Statistical distribution of actual electricity consumption of users in summer weekend.

After simulating the behavior data of the above users through the electricity demand model, the electricity consumption data of each electric appliance is obtained, as shown in Figure 3-4. It can be seen that the distribution is basically the same as the actual statistical analysis.



(a) Simulation of electricity consumption distribution of consumers using electrical appliances in working days and summer



(b) Simulation of electricity consumption distribution of consumers using electrical appliances in summer on weekends

Figure 3-4 simulation of electricity consumption distribution of consumers using electrical appliances in summer

3.3.3 Characteristic analysis of typical energy supply equipment

（1）PV

Distributed roof photovoltaic (DPPV) is one of the cores of DSM power supply system promotion. At present, many countries have put forward the policy of subsidizing the grid price of distributed PV. There are many types of photovoltaic cells. The technical performance comparison of various photovoltaic cells is shown in Table 3-2. At present, monocrystalline silicon and polycrystalline silicon solar cells are widely used in the world.

Table 3-2 Technical performance comparison of solar cells

Number	Comparison project	Monocrystalline silicon	Polysilicon	Amorphous silicon
1	Technology maturity	The technology of commercial single crystal silicon battery has reached the mature stage.	At present, ingot polycrystalline silicon technology is commonly used.	After more than 30 years of development, the technology has become increasingly mature and constantly improved.
2	Photoelectric conversion efficiency	Commercial batteries are generally 13% - 18%.	Commercial batteries generally 12% ～ 16%.	Commercial batteries are generally 5% - 9%.
3	Price	Recently, the price has dropped and gradually approached polysilicon.	The total production cost is lower than that of monocrystalline silicon.	The total production cost is the lowest.
4	Adaptability to light, temperature and other external environment	The output power is directly proportional to the light intensity, and the efficiency is not fully played at high temperature.	The output power is directly proportional to the light intensity, and the efficiency is not fully played at high temperature.	The weak light response is good and the charging efficiency is high. High temperature performance is good, and the influence of temperature is smaller than that of crystalline silicon solar cells.

（2）Battery

The application of battery in the demand side mainly comes from the promotion and application of peak valley electricity price. Batteries can store electricity at low prices and use them at high prices. Although it does not have the ability to generate electricity, it can reduce the energy cost by reducing the peak load and filling the valley of the power demand on the demand side. As shown in Table 3-3, the characteristics of different types of batteries are compared.

Table 3-3 Characteristic comparison of different types of batteries

	Lead acid battery	Sodium sulfur battery	Lithium battery	Nickel battery
Energy density, Wh/kg	35	110	120	60
Charge discharge power, %	87	90	95	90
Service life, h	4500	4500	3500	2000
Cost 10^4Yen/kWh	5	2.5	20	10
Purpose	Vehicle, emergency power supply	Load leveling, emergency power supply, household power supply	Load leveling, vehicle, power bank	Vehicle, power bank

The battery state SOC(t) of the battery means:

$$\mathrm{SOC}(t)=\frac{Q_r(t)}{Q}$$

where, $Q_r(t)$ is the remaining capacity of the battery at time t, Q is the maximum capacity of the battery.

The limits of battery charging and discharging power and battery state are as follows:

$$-P_{bmax}\le P_b(t)\le P_{bmax}$$

$$SOC_{min}\le SOC(t)\le SOC_{max}$$

where, P_{bmax} is the maximum charging and discharging power of the battery, which is generally 15% - 25% of the demand side capacity; $SOC(t)$ is the battery state of the battery in t period; SOC_{min} is the minimum value of battery state of charge; SOC_{max} is the maximum state of charge of the battery. SOC_{min}和SOC_{max} are called the discharge depth of the battery.

（3）CHP

Demand side cogeneration is a hot spot in recent years, which uses natural gas, internal combustion engine or fuel cell and other equipment to generate electricity while using waste heat for heating or domestic hot water supply. In some cases, absorption refrigeration unit will be used to supply air conditioning cooling load by using waste heat.

3.4 Electricity price theory and reward and punishment mechanism

The fulcrum of electricity market is the price of electricity, and the formulation of electricity price is the most important content in the power market. Many failure examples in foreign countries are due to the adverse impact of price shocks on power system reliability and security in the electricity market environment. How to quickly calculate the reasonable electricity price and how to distribute the transmission cost to each user fairly and reasonably are the hot research issues.

3.4.1 Basic definition of electricity price

Electricity price is the abbreviation of electricity price. In a market economy, every commodity has a price that shows its value. Electricity is a special commodity and has its specific price. Therefore, electricity price is the monetary expression of the value of electricity commodity in the process of generation, supply and use exchange. According to the price chain of the whole process of power generation, supply and marketing, electricity price is divided into two types: the on-grid price of power generation company, the transmission and distribution price of power grid company and the terminal sales price [4]. At present, China's electricity price system only includes on grid price and sales price. The transmission and distribution price are still in the initial stage of reform, and there is no independent transmission and distribution price system for the time being. Among them, power generation companies and power grid companies are the producers and suppliers of electric energy commodities, and the vast number of power users are the demanders and consumers of power commodities.

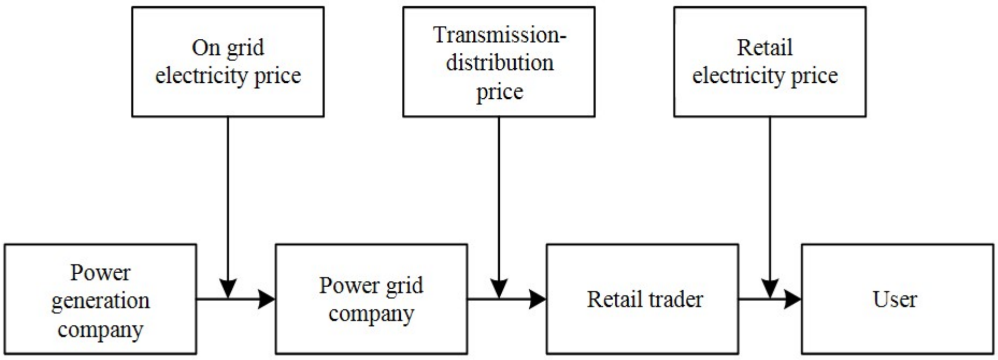


Figure 3-5 Diagram of power generation, transmission and distribution, power supply and consumption system

As shown in Figure3-5, the process of power supply also constitutes the formation process of electricity price, which successively forms the on-grid price, transmission and distribution price and final user price. The on-grid price can be called the generation price, that is, the ex factory price of the energy generated by the power plant, which reflects the scarcity of power generation resources and the cost difference. The power supply structure can be rationalized by adjusting it. The generation price is composed of generation cost, generation profit and price tax. Transmission and distribution price, also known as grid price, refers to the price of electricity sold to distribution companies by owners of high-voltage or ultra-high-voltage transmission or circuit. It is similar to the price of general goods sold to retailers and wholesalers, so it can also be used as wholesale electricity price to reflect the consumption of transmission and generation resources, to regulate the construction of transmission network and to solve the allocation of power resources in rich and poor areas. Transmission and distribution price are mainly composed of power purchase cost, transmission and distribution cost, transmission and distribution profit and tax. The price of electricity sales is the price of electricity sold by distribution companies to end users. It is similar to the retail price of general commodities. It is also known as user price or retail price, which reflects the impact of users on power supply cost. The final sale price consists of power purchase cost from power grid, transmission and distribution cost, electricity sales profit and tax [5].

To sum up, electricity price is a system, which is the aggregation of various object electricity prices. From the perspective of circulation process, electricity price can be divided into on grid price, transmission and distribution price and terminal sales price. (As seen at Table 3-4)

Table 3-4 Summary of electricity price system and its basis and function

Classification	Form of electricity price	Basis and function
Circulation process	Generation price	Reflect the scarcity of power generation resources and cost differences, adjust the power structure.
	Transmission-distribution price	Reflect the transmission and generation resource consumption, adjust the transmission network layout.
	Selling price	Reflect the influence of different consumption modes on power supply cost and adjust consumption structure.

3.4.2 Dynamic electricity price

Dynamic electricity price refers to a kind of electricity price x made according to the electricity consumption in the power consumption cycle, which changes with the change of electricity consumption. In practical application, a kind of dynamic electricity price that we often use is the step price:

$$\alpha(q) = \begin{cases} \alpha_1 \ , & q \le q^* \\ \alpha_2, & q > q^* \end{cases} \tag{2.1}$$

Among them, α_1 is the unit price within the first stage of electricity consumption, α_2 is the unit price within the scope of the second stage power consumption, q^* is the dynamic electricity price segment point consumption, and $\alpha_2 > \alpha_1$.

3.4.3 Real-time price

The real-time price refers to a kind of electricity price $\alpha(t)$ which is set in the period of electricity consumption according to the time of electricity consumption or time interval. This price varies with the time of electricity consumption. In smart grid, the two-way real-time communication system and advanced metering system established by power operation system and users can ensure the accuracy of power billing. In the actual operation of power grid, the load of power grid is often closely related to the production plan and power consumption of users. One of the key factors affecting the load of power grid is to expand the real-time price to guide users to make production plan through real-time price.

The frequency of electricity price adjustment is too high, which is not conducive to the user to formulate production plan and power consumption plan. In extreme cases, the loss caused by user shutdown exceeds the increased power consumption cost due to the increase of electricity price, which makes the effect of guiding users to formulate power consumption plan by adjusting the price of electricity is limited [6]. On the contrary, the electricity price adjustment cycle is too long to achieve the expected effect. At the same time, the proportion of electricity consumption cost in different industries varies greatly, so the impact of the same price adjustment on different industries is also obvious. In the process of making real-time price, it is the priority to adopt different pricing mechanism for different industries and different user groups, so as to formulate a reasonable real-time price and realize the effective management of user resources.

In practical application, a kind of real-time price is time of use price. The so-called time-of-the-art price is the time-sharing step-by-step electricity price, which divides a day into three periods of peak, average and valley according to the peak and trough of the load curve, and corresponds to the three kinds of electricity prices: peak, average and valley [7]. The electricity price is shown in formula (2.2).

$$\alpha(t)=\begin{cases}\alpha_1, & 0\le t<t_1\\ \alpha_2, & t_1\le t<t_2\\ \alpha_3, & t_2\le t<t_3\end{cases} \tag{2.2}$$

When designing time of use price, there is a higher peak price in peak period and a lower valley price in valley period. That is, by increasing the electricity price in peak period and reducing the electricity price in low power consumption period, users can be encouraged to change their power consumption mode economically, so as to alleviate the power shortage in peak period and tap the power demand in low valley period. Therefore, the time of use of peak valley price can achieve the purpose of reducing peak load and filling valley and improving load curve.

Time of use price is an economic means adopted by the power industry to implement demand side management to encourage users to change their power consumption mode and avoid peak load, so as to achieve peak shaving and valley filling, improve the load rate of power system and stable operation [8]. In foreign countries, time of use price has been well applied and achieved good results. Now it has been popularized in China. As an effective demand side management method, time of use price has been widely used in foreign countries, and there are many places in China to implement the overtime price.

There are many factors that affect the power consumption of users at a certain time. Generally speaking, they are closely related to the electricity price, weather conditions, production conditions, shift system, economic policies and other factors. However, from the perspective of practical operability and target management, electricity price is a better control object. Therefore, in the user response model of time of use price, the price is considered as the main factor, while other macro factors or factors that cannot be measured temporarily are simplified. The determination of TOU price mainly includes two aspects: the division of peak valley period and the determination of corresponding peak valley price. The division of peak and valley periods must be consistent with the actual situation of load curve, otherwise the time of use price will lose its significance of application and may even mislead the user's power consumption mode. How to operate, we should consider the following issues:

（1）The division of time period should reflect the actual situation in line with the curve correctly, otherwise the time of use price will lose its corresponding significance.

（2）The division of time period should not be too detailed, it should be conducive to the adjustment of power consumption structure.

（3）The electricity price in valley period should not be set too low, and the electricity sales income in valley period must not be less than the generation cost, that is, the electricity price in valley period is greater than or equal to the marginal cost of power system in that period.

（4） The difference between peak and valley prices should not be too large, otherwise there will be the phenomenon of peak-valley inversion, which is contrary to the original intention of implementing TOU

（5） The interests of power supply companies must be guaranteed in the implementation of TOU price. If users only consider using low-cost electricity, it will certainly reduce the income of the power supply company. In addition to improving the reliable power consumption for users, power supply companies also shoulder the task of power grid construction, so this point also needs to be considered.

Generally speaking, large consumers of electricity will actively respond to this policy, and their enthusiasm for charge transfer is also very high, which is the main force to realize peak shaving and valley filling. Because the electricity charge is a big expense. If the TOU price is implemented, it can not only achieve the purpose of cutting peak and filling valley, but also make the power supply company and users benefit. This is the best embodiment of this policy.

3.4.4 Reward and punishment mechanism

Electricity is also a commodity, so it has the general characteristics of a commodity. In the electricity market, the balance between supply and demand of electricity should also conform to the general economic law of commodities, that is, due to the different demands of consumers, the relationship between supply and demand in a certain period of time is also different. When the supply is less than the demand, it will lead to the shortage of power supply of power companies and users; when the supply exceeds the demand, it will cause idle and waste of power resources. As the user behavior is autonomous behavior, they usually use electricity freely according to their own preferences and habits, which may lead to electricity consumption in peak period, that is, unreasonable power consumption, resulting in structural shortage of power. In order to solve the contradiction between supply and demand, power companies can formulate a price strategy with reward and punishment mechanism to guide users to use electricity reasonably. This kind of reward and punishment mechanism should be based on the effective restriction and improvement of users' electricity consumption behavior, so that they can actively avoid peak load and stagger peak load, at the same time, the power company can better allocate and dispatch power resources. The implementation of the real-time price strategy with reward and punishment mechanism can reduce the power demand of users in the peak electricity consumption meeting, and appropriately relieve the power supply pressure; at the low power consumption summit, it can encourage users to use more electricity. Therefore, the power supply and demand can be adjusted by the price of electricity, the efficiency of power use can be improved, and the balance of power supply and demand can be realized.

The electricity price strategy with reward and punishment mechanism can be generally divided into dynamic reward and punishment and real-time reward and punishment. Based on the dynamic electricity price, the price strategy with reward and punishment mechanism is $\alpha + k(q,q^*)$, where α is the base price, $k(q,q^*)$ is the price of reward and punishment, q^* is the expected power consumption, when $k(q,q^*) < 0$ is the incentive price, on the contrary, it is the penalty price. Based on the real-time price, the price strategy with reward and punishment mechanism is $\alpha(t) + k(p(t), p^*(t))$, where $\alpha(t)$ is the basic spot price, $k(p(t), p^*(t))$ is the reward and punishment price determined according to the load, $p^*(t)$ is the desired load curve, when $k(p(t), p^*(t)) < 0$ is the incentive price, on the contrary, it is the penalty price. In addition, according to the specific implementation mode and object of reward and punishment, it can be divided into linear and nonlinear, unilateral and bilateral.

3.4.4.1 Linear reward and punishment electricity price and electricity charge collection strategy

（1）Unilateral linear penalty and nonlinear charge

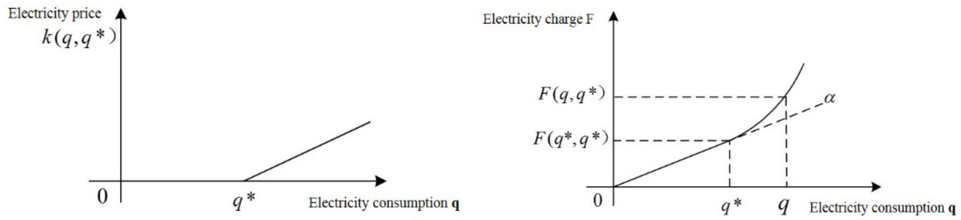
The unilateral linear penalty price and nonlinear charging model are shown in Figure 3-6:

$$k(q,q^*) = \begin{cases} 0, & q \le q^* \\ \mu(q-q^*), & q > q^* \end{cases} \tag{4.2}$$

$$\begin{aligned} F(q,q^*) &= \begin{cases} \alpha q, & q \le q^* \\ (\alpha + \mu(q-q^*))q, & q > q^* \end{cases} \\ &= \begin{cases} \alpha q, & q \le q^* \\ \alpha q + \mu q(q-q^*), & q > q^* \end{cases} \end{aligned} \tag{4.3}$$

where, μ is the penalty coefficient, μq is the incremental penalty price. The closer the user's actual power consumption q is to the expected power consumption q^* of the power company, the smaller the penalty price of the excess part $q-q^*$（$q>q^*$） will be.

This kind of tariff collection strategy does not encourage people to use too much electricity, which is suitable for the situation of shortage of power resources and shortage of electricity market.



（a）Unilateral linear penalty price （b）Unilateral nonlinear electricity charge collection strategy

Figure 3-6 Unilateral linear penalty tariff and nonlinear tariff collection strategy

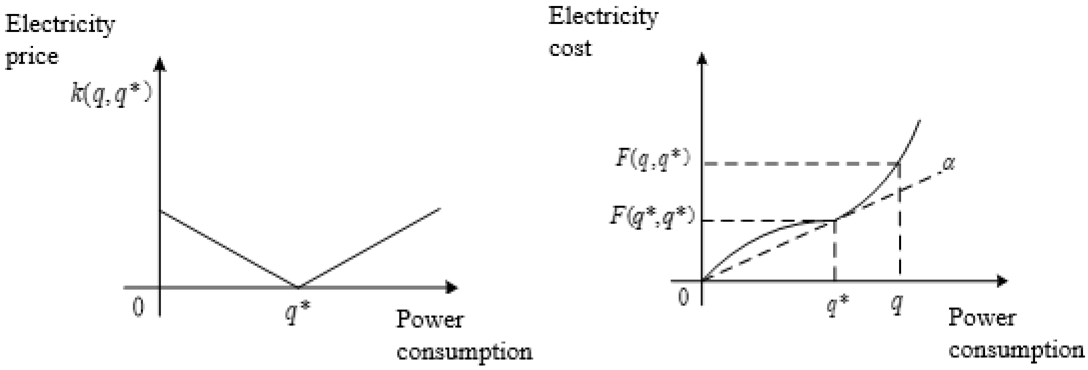
（2）**Bilateral linear penalty and nonlinear charge**

The bilateral linear penalty price and nonlinear charging model are shown in Figure 3-7:

$$k(q,q^*) = \mu|q - q^*| \tag{4.4}$$

$$\begin{aligned} F(q,q^*) &= (\alpha + \mu|q - q^*|)q \\ &= \alpha q + \mu q|q - q^*| \end{aligned} \tag{4.5}$$

This kind of tariff collection strategy does not encourage either excessive use of electricity or less consumption of electricity. This charging mode encourages users to use electricity as close as possible to the expected electricity consumption q^*, because the closer the user's actual electricity consumption q is to the expected power consumption q^*, the lower the unit power consumption cost will be.



（a）Bilateral linear penalty pricing （b）Bilateral nonlinear tariff collection strategy

Figure 3-7 Bilateral linear penalty tariff and nonlinear tariff collection strategy

（3）Bilateral linear rewards and punishments and nonlinear charges

The unilateral linear reward and penalty price and nonlinear charging model are shown in Figure

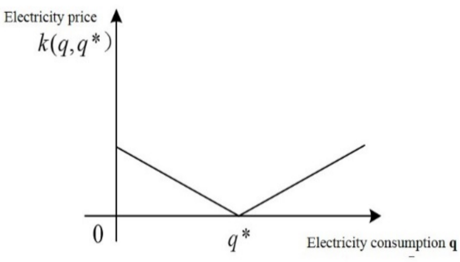
3-8:

$$k(q,q^*)=\mu|q-q^*|-\Delta \tag{4.6}$$

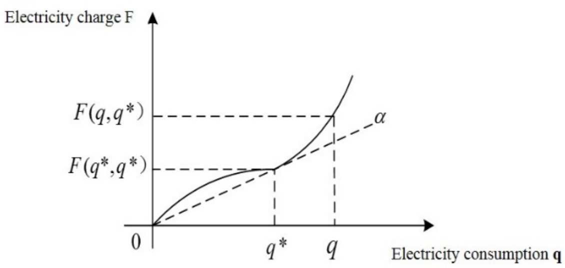
$$\begin{aligned}F(q,q^*)&=(\alpha+\mu(|q-q^*|-\Delta))q\\&=\alpha q+\mu q(|q-q^*|-\Delta)\end{aligned} \tag{4.7}$$

where, Δ is the margin of rewards and punishments; when $|q-q^*|>\Delta$, $k(q,q^*)$ is the penalty price, when $|q-q^*|<\Delta$, $k(q,q^*)$ is the incentive price.

This strategy encourages users to use electricity according to the expected power consumption q^*. If the deviation between the actual power consumption and the expected power consumption exceeds the reward and punishment margin, the punitive charge will be implemented, otherwise, the incentive charge will be implemented.



(a) Bilateral linear incentive price



(b) Bilateral nonlinear tariff collection strategy

Figure 3-8 Bilateral linear incentive and penalty pricing and nonlinear tariff collection strategy

Based on the electricity charge collection strategy of formula (4.7), the actual electricity consumption of users is encouraged to be as close as possible to the expected power consumption q^*. In this charging mode, rewards and punishments are charged according to the deviation between the actual consumption of electricity and the expected power consumption. If the deviation exceeds the margin of rewards and punishments, punitive charges will be imposed, otherwise, incentive charges will be implemented.

3.4.4.2 Nonlinear rewards and punishments and electricity charge collection strategy

(1) Unilateral nonlinear penalty and linear charge

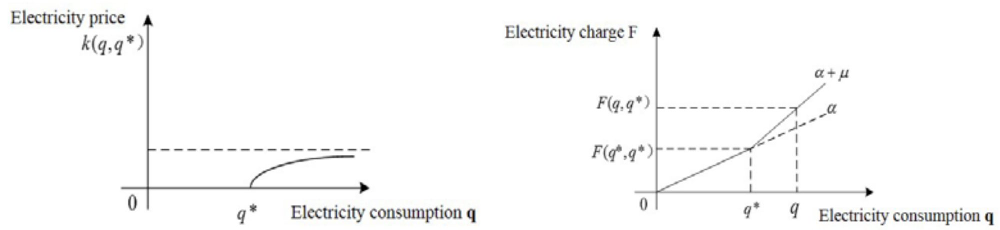
The unilateral nonlinear penalty price and linear charging model are shown in Figure 3-9:

$$k(q,q^*)=\begin{cases}0, & q\le q^* \\ \mu(q-q^*)/q, & q>q^*\end{cases} \tag{4.8}$$

$$\begin{aligned}F(q,q^*)&=\begin{cases}\alpha q, & q\le q^* \\ (\alpha q+\mu(q-q^*)/q)q, & q>q^*\end{cases} \\ &=\begin{cases}\alpha q, & q\le q^* \\ \alpha q+\mu(q-q^*), & q>q^*\end{cases} \\ &=\begin{cases}\alpha q, & q\le q^* \\ \alpha q^*+(\alpha+\mu)(q-q^*), & q>q^*\end{cases}\end{aligned} \tag{4.9}$$

where, μ is the incremental penalty price, or penalty price, $\mu=\lim\limits_{q\to\infty}k(q,q^*)$.

As can be seen from figure 4.4 (b), this unilateral non-linear penalty price and linear charging strategy are essentially a kind of step tariff collection mode, where $\alpha+\mu$ is the second step tariff.



（a）Unilateral nonlinear penalty price （b）Collection strategy of unilateral linear tariff

Figure 3-9 Collection strategy of nonlinear penalty price and linear price

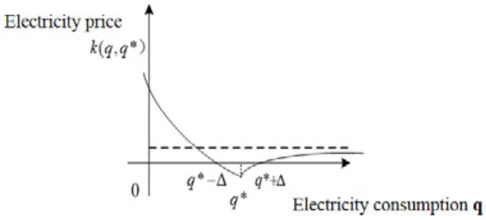
（2）Bilateral nonlinear rewards and punishments and near linear charges

The two-sided nonlinear incentive and penalty pricing model and the near linear charging model are shown in Figure 3-10:

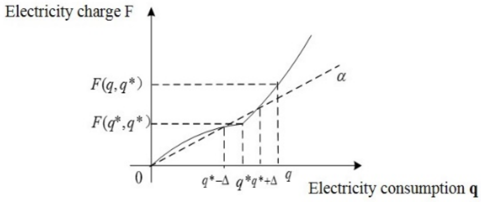
$$k(q,q^*)=\mu(|q-q^*|-\Delta)(q+\varepsilon) \tag{4.10}$$

$$\begin{aligned}F(q,q^*)&=(\alpha+\mu(|q-q^*|-\Delta)/(q+\varepsilon))q \\ &=\alpha q+(\mu q/(q+\varepsilon))(|q-q^*|-\Delta)\end{aligned} \tag{4.11}$$

where, Δ is the power margin for rewards and punishments, $\varepsilon>0$ is a small positive number.



(a) Bilateral nonlinear penalty pricing



(b) Collection strategy of bilateral near linear tariff

Figure 3-10 Bilateral nonlinear penalty tariff and near linear tariff collection strategy

3.5 Optimal user load distribution based on real time tariff collection strategy

Nowadays, the commonly used electricity price can be divided into fixed price, step price, time of use price and spot price. Fixed electricity price is a collection method of electricity fee that does not change with time and electricity consumption. This kind of price charging is relatively simple, but it has no regulatory effect on the relationship between supply and demand in the power market [9,10]. Step tariff is a kind of dynamic electricity price formulated according to the power consumption section of the payment interval. It shows that the more power consumption, the higher the unit power consumption cost, and the unit power consumption cost changes nonlinearly with the increase of electricity consumption. This kind of electricity price can effectively restrain the demand of users through the price, so as to achieve the purpose of energy conservation and emission reduction [7]. Time of use price, also known as peak valley price, is a segmented real-time price formulated according to the peak and valley periods of daily electricity consumption. The price of electricity in peak period is higher than that in low period. This kind of price encourages users to avoid peak load and stagger peak load, which is conducive to load balance of power grid [8]. The real real-time price should be a kind of electricity price which changes dynamically with time or load. It is an ideal instantaneous dynamic price in space. This price mechanism has a strong induction and regulation effect on the electricity consumption mode of users [6]. In theory, the absolute real-time price can solve some problems of current electricity price, but the actual operation will be quite difficult, and there is no foundation and condition for implementation at present.

Therefore, we can design a kind of real-time price which can be operated on the basis of time of use price. Based on TOU price and user load, this paper proposes a real-time price strategy with dynamic reward and punishment mechanism dominated by both supply and demand sides. Based on this, the optimal allocation of user load is studied, and the optimal allocation model and algorithm of user load are given.

3.5.1 Electricity charge collection strategy based on real time price

The electricity charge collection strategy based on real-time price is a kind of electricity charge collection strategy based on the real-time load of users:

$$F(p,a,b)=\int_a^b \alpha(t)p(t)dt \tag{5.1}$$

where, $[a,b]$ is the collection time period of electricity charges, $\alpha(t)$ is the real-time price, $p(t)$ is the user's real-time load.

If fixed electricity price is adopted, $\alpha(t)\equiv\alpha$ is taken, Formula (5.1) is changed into a charging mode according to the electricity consumption in $[a,b]$ time zone:

$$\int_a^b \alpha(t)p(t)dt = \alpha q(a,b) \tag{5.2}$$

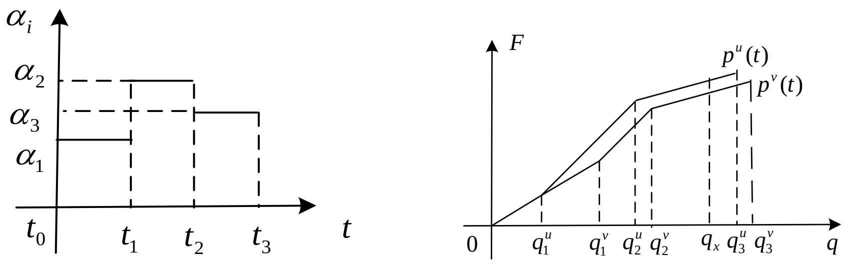
where, $q(a,b)=\int_a^b p(t)dt$ is the power consumption of time zone $[a,b]$.

If the time of use price is taken, that is, when $\alpha(t)=\alpha_i$, $t_{i-1}\le t<t_i$, $i=1,2,\cdots,n$, $t_0=a$, $t_n=b$ is taken, Then formula (5.1) is changed into a mode of collecting electricity charges according to $[a,b]$ time zone by time:

$$F(p,a,b)=\sum_{i=1}^{n}\alpha_i\int_{t_{i-1}}^{t} p(t)dt \tag{5.3}$$

where, α_i is the unit price of the i period.

Time of use price is an operational real-time price. When collecting electricity charges according to time of use price, there will be a big difference between the same electricity consumption of different load curves. In fact, there is a reward and punishment mechanism implied in the TOU payment mode, which encourages people to use electricity at low price and avoid peak load. Figure 3-11 shows the TOU price and tariff collection strategy of $n=3$, (a) is the unit price of each period; (b) is the payment curve of two different electricity consumption modes, where, $q_i^u=\int_{t_0}^{t_i} p^u(t)dt$, $q_i^v=\int_{t_0}^{t_i} p^v(t)dt$. As can be seen from Fig. 5.1 (b), in period $[t_0,t_1]$, $q_1^v>q_1^u$; in period $[t_1,t_2]$, $(q_2^u-q_1^u)>(q_2^v-q_1^v)$; Users use more electricity when the electricity price is high in stage according to $p^u(t)$. As a result, the overall electricity consumption is small and more payment is needed, that is when $q_3^v>q_3^u$, $F(p^v(t))<F(p^u(t))$.



(a)Time of use price (b)Payment curve

Figure 3-11 Time of use tariff and tariff collection strategy at $n=3$

Power companies can increase the electricity price in the peak period and reduce the electricity price in the low period, stimulate and encourage users to actively change their consumption behavior and power consumption mode, so as to achieve the purpose of peak load shifting and valley filling, so as to alleviate the power supply tension during peak load, improve the operation efficiency and stability of the power system, and users can also get preferential tariff service.

3.5.2 Real time price with dynamic reward and punishment mechanism

If the real-time price is adopted, it has the following functions: (1) by setting a relatively high unit price in the period of tight power supply and a relatively low unit price in the period of more abundant power supply, it can induce users to use electricity at low price; (2) According to the demand of different users, the personalized real-time price $\alpha(t-t_s)$ is formulated, so that the user can determine the best power consumption mode according to the principle of maximum profit.

Different operational real-time price strategies for different users should not only reflect the overall balance of power load distribution, but also take into account the fairness of all users. For this reason, we propose a real-time dynamic reward and punishment mechanism to collect electricity charges:

$$F(p_s, p_s^*) = \int_a^b (\alpha(t-t_s) + k(p_s(t), p_s^*(t))) p_s(t) dt \quad (5.4)$$

where, $\alpha(t)$ is the basic real-time price in the time-sharing form with period $[a,b]$, $p_s(t)$ is the actual power load of the user; $p_s^*(t)$ is the expected power load; $k(p_s(t), p_s^*(t))$ is the real-time dynamic incentive price, when $k(p_s(t), p_s^*(t)) < 0$, is the real-time dynamic incentive price, when $k(p_s(t), p_s^*(t)) > 0$, is the real-time dynamic penalty price, $k(p_s^*(t), p_s^*(t)) \leq k(p_s(t), p_s^*(t))$.

The fairness of formula (5.4) is reflected in the implementation of unified basic real-time price strategy α and real-time dynamic reward and punishment mechanism k for each user. The difference is reflected in different time delay t_s and expected load $p_s^*(t)$ and actual load $p_s(t)$ for different users. $k(p_s(t), p_s^*(t))$. The following two-sided linear symmetric rewards and punishments can be adopted:

$$k(p_s(t), p_s^*(t)) = \mu(\left|p_s(t) - p_s^*(t)\right| - \Delta) \tag{5.5}$$

where, $\mu \geq 0$ is the reward and punishment coefficient, $\Delta \geq 0$ is the load margin for implementing rewards and punishments.

3.5.3 Optimal user load distribution based on real time price

(1) User declaration principle

For user $s \in S$, the real-time expected power load can be determined based on the user declaration principle, that is $p_s^*(t) = \hat{p}_s(t)$, At this time, the user's electricity fee collection model based on real-time price is as follows:

$$F(p_s, \hat{p}_s) = \int_a^b (\alpha(t - t_s) + k(p_s(t), \hat{p}_s(t)))p_s(t)dt \tag{5.6}$$

where, $\hat{p}_s(t)$ is the expected power load declared by the user.

This strategy allows users to dynamically adjust the expected power load during the payment period according to their own demand changes, so that the power company can reasonably and dynamically organize power production and implement power dispatching according to the expected power load declared by users in the grid.

(2) The principle of minimum electricity cost for consumers

The principle of minimum user cost is to determine $p_s^*(t)$ from the point of view of minimum power consumption cost:

$$p_s^*(t) = \arg\min_{p_s(t)} \int_a^b \alpha(t - t_s)p_s(t)dt \tag{5.7}$$

$s.t.$

$$\int_a^b p_s(t)dt = q_s \tag{5.8}$$

$$\begin{cases} p_{s\min} \leq p_s(t) \leq p_{s\max} \\ t \in [a,b] \end{cases} \tag{5.9}$$

where, q_s is the total power consumption required by the user, $p_{s\max}$ is the maximum power load of the user, $p_{s\min}$ is the minimum power load of the user.

When the unit power cost is low, the total electricity consumption cost can be reduced by using more electricity. Therefore, it can be proved that the optimal solution of the above problem is $p_s^*(t)$:

$$p_s^*(t) = \begin{cases} p_{s\max}, & t \in T \\ 0, & t \notin T \end{cases} \tag{5.10}$$

where, T is the time section of actual generating power load.

$$T \subseteq \{t | \alpha(t - t_s) \le \alpha_s^*, t \in [a,b]\} \tag{5.11}$$

$$T \cup T_1 = \{t | \alpha(t - t_s) \le \alpha_s^*, t \in [a,b]\} \tag{5.12}$$

$$T_1 = \{t | \alpha(t - t_s) = \alpha_s^*, t \in [a,b]\} \tag{5.13}$$

$$p_{s\max} \int_{t \in T} dt = q_s \tag{5.14}$$

prove that: assuming that $p_s(t) = p_s^*(t) + \Delta p_s(t)$, $\int_a^b p_s(t)dt = q_s$ $p_{s\min} \le p_s(t) \le p_{s\max}$, $\int_a^b p_s^*(t)dt = q_s$, $\int_a^b \Delta p_s(t)dt = 0$. According to formula (5.10), there is $\Delta p_s(t) \le 0, t \in T$; $\Delta p_s(t) \ge 0, t \notin T$; and $\int_a^b \Delta p_s(t)dt = -\int_{t \in T} |\Delta p_s(t)| dt + \int_{t \notin T} |\Delta p_s(t)| dt = 0$.

and because that $\alpha(t - t_s) \le \alpha_s^*, t \in T$, $\alpha(t - t_s) \ge \alpha_s^*, t \notin T$, so that,

$$
\begin{aligned}
&\int_a^b \alpha(t-t_s)p_s(t)dt \\
&=\int_a^b \alpha(t-t_s)(p_s^*(t)+\Delta p_s(t))dt \\
&=\int_a^b \alpha(t-t_s)p_s^*(t)dt+\int_{t\in T}\alpha(t-t_s)\Delta p_s(t)dt+\int_{t\notin T}\alpha(t-t_s)\Delta p_s(t)dt \\
&=\int_a^b \alpha(t-t_s)p_s^*(t)dt-\int_{t\in T}\alpha(t-t_s)\left|\Delta p_s(t)\right|dt+\int_{t\notin T}\alpha(t-t_s)\left|\Delta p_s(t)\right|dt \\
&\geq\int_a^b \alpha(t-t_s)p_s^*(t)dt+\alpha_s^*(-\int_{t\in T}\left|\Delta p_s(t)\right|dt+\int_{t\notin T}\left|\Delta p_s(t)\right|dt) \\
&=\int_a^b \alpha(t-t_s)p_s^*(t)dt
\end{aligned}
$$

The proof is complete.

(3) The principle of maximum profit for users

The principle of maximum user income is to determine $p_s^*(t)$ according to the maximum net income of users, that is:

$$p_s^*(t)=\arg\max_{p_s(t)}\{U_s(q_s)-\int_a^b \alpha(t-t_s)p_s(t)dt\} \tag{5.15}$$

$s.t.$

$$\int_a^b p_s(t)dt=q_s \tag{5.16}$$

$$\begin{cases} p_{s\min}\leq p_s(t)\leq p_{s\max} \\ t\in[a,b] \end{cases} \tag{5.17}$$

where, $U_s(q_s)$ is the utility function of resident user s, U is a monotone concave function [11].

Similarly, it can be proved that the optimal solution of the problem is $p_s^*(t)$:

$$p_s^*(t)=\begin{cases} p_{s\max}, & t\in T \\ 0, & t\notin T \end{cases} \tag{5.18}$$

where, T is the time period of actual generation of electrical load,

$$T \subseteq \{t \mid \alpha(t-t_s) \le \alpha_s^*, t \in [a,b]\} \tag{5.19}$$

$$T \cup T_1 = \{t \mid \alpha(t-t_s) \le \alpha_s^*, t \in [a,b]\} \tag{5.20}$$

$$T_1 = \{t \mid \alpha(t-t_s) = \alpha_s^*, t \in [a,b]\} \tag{5.21}$$

$$q_s^* = \int_a^b p_s^*(t)dt = p_{s\max} \int_{t \in T} dt \tag{5.22}$$

$$U_s'(q_s^*) = \alpha_s^* \tag{5.23}$$

prove that: assuming that $p_s(t) = p_s^*(t) + \Delta p_s(t)$, so that $\int_a^b p_s(t)dt = q_s^* + \Delta q_s = q_s$, $q_s^* = \int_a^b p_s^*(t)dt$, $\Delta q_s = \int_a^b \Delta p_s(t)dt$.

According to the formula (5.18), there is $\Delta p_s(t) \le 0$, $t \in T$; $\Delta p_s(t) \ge 0$, $t \notin T$; and $\int_a^b \Delta p_s(t)dt = \int_{t\in T} \Delta p_s(t)dt + \int_{t \notin T} \Delta p_s(t)dt = -\int_{t\in T} |\Delta p_s(t)|dt + \int_{t\notin T} |\Delta p_s(t)|dt = \Delta q_s$.

because that $\alpha(t-t_s) \le \alpha_s^*, t \in T$, $\alpha(t-t_s) \ge \alpha_s^*, t \notin T$, so that:

$$\begin{aligned}
& U_s(q_s) - \int_a^b \alpha(t-t_s) p_s(t)dt \\
&= U_s(q_s^* + \Delta q_s) - \int_a^b \alpha(t-t_s)(p_s^*(t) + \Delta p_s(t))dt \\
&= U_s(q_s^*) + U_s(q_s^* + \Delta q_s) - U_s(q_s^*) - \int_a^b \alpha(t-t_s) p_s^*(t)dt + \int_{t\in T} \alpha(t-t_s)|\Delta p_s(t)|dt - \int_{t\notin T} \alpha(t-t_s)|\Delta p_s(t)|dt \\
&\le U_s(q_s^*) + \frac{U_s(q_s^* + \Delta q_s) - U_s(q_s^*)}{\Delta q_s}\Delta q_s - \alpha_s^*(-\int_{t\in T}|\Delta p_s(t)|dt + \int_{t\notin T}|\Delta p_s(t)|dt) - \int_a^b \alpha(t-t_s) p_s^*(t)dt \\
&= U_s(q_s^*) + \frac{U_s(q_s^* + \Delta q_s) - U_s(q_s^*)}{\Delta q_s}\Delta q_s - \alpha_s^* \Delta q_s - \int_a^b \alpha(t-t_s) p_s^*(t)dt
\end{aligned}$$

when $\Delta q_s \to 0$, if $U_s'(q_s^*) = \alpha_s^*$, there has:

$$U_s(q_s) - \int_a^b \alpha(t-t_s)p_s(t)dt$$
$$\le U_s(q_s^*) + U_s'(q_s^*)\Delta q_s - \alpha_s^*\Delta q_s - \int_a^b \alpha(t-t_s)p_s{}^*(t)dt$$
$$= U_s(q_s^*) - \int_a^b \alpha(t-t_s)p_s{}^*(t)dt$$

The proof is complete.

(4) Minimum cost principle of comprehensive power consumption in power grid

The principle of minimizing the comprehensive power consumption cost of power grid is to determine the user load $\{p_s^*(t)\}$ to minimize the comprehensive weighted power consumption cost:

$$\{p_s^*(t)\} = \arg\min_{p_s(t)} \sum_s \lambda_s \alpha(t-t_s)p_s(t)dt \tag{5.24}$$

$s.t.$

$$\int_a^b p_s(t)dt = q_s \tag{5.25}$$

$$\begin{cases} p_{s\min} \le p_s(t) \le p_{s\max} \\ t \in [a,b] \end{cases} \tag{5.26}$$

$$\begin{cases} \sum_i a_{is} p_s(t) \le b_i \\ i = 1,2,\cdots,m \end{cases} \tag{5.27}$$

where, a_{is} is the power distribution coefficient, $0 \le a_{is} \le 1$, $\sum_i a_{is} = 1$; b_i is the rated load of the i-th power supply unit.

(5) Principle of maximum comprehensive income of power grid

Determining the user load $\{p_s^*(t)\}$ can also maximize the comprehensive weighted benefit:

$$\{p_s^*(t)\} = \arg\max_{p_s(t)} \sum_s \lambda_s \{U_s(q_s) - \int_a^b \alpha(t-t_s)p_s(t)dt\} \tag{5.28}$$

$s.t.$

$$\int_a^b p_s(t)dt = q_s \tag{5.29}$$

$$\begin{cases} p_{s\min} \le p_s(t) \le p_{s\max} \\ t \in [a,b] \end{cases} \tag{5.30}$$

$$\begin{cases} \sum_i a_{is} p_s(t) \le b_i \\ i = 1,2,\cdots,m \end{cases} \tag{5.31}$$

3.5.4 User load and electricity price algorithm based on Stackelberg strategy

In the power market environment, power enterprises and users are two players in the game. They are not only the opposite business relationship, but also the interdependent and interactive cooperative relationship. Their game goal is to maximize their own interests, so they are decision makers with independent decision-making power. In the game, electric power enterprises undoubtedly need to maximize their own profits or social benefits, and their decision variables are the quantity of electric energy supply, which reflects the power supply capacity and social responsibility of power enterprises, while the decision variables of users are actual power consumption or actual power consumption load.

Based on the real-time price strategy proposed in this paper, the game process can be simply expressed as follows: (1) power enterprises take action first, and formulate reasonable electricity fee collection policies with dynamic reward and punishment mechanism (basic real-time price, dynamic reward and punishment model) according to the actual situation of users; (2) Then, according to the principle of minimum cost or maximum profit, the user determines the best power consumption mode (optimal power load).

Obviously, the above game is a typical Stackelberg game problem [12,13], in which the power enterprise is the main party and the user is the subordinate party. According to the principle of maximum profit, the secondary user can determine the optimal electricity load $p_s^{**}(t)$ and the electricity fee to be paid $F(p_s^{**}, p_s^{*})$:

$$p_s^{**}(t) = \arg\max_{p_s(t)} \sum_s \lambda_s \{U_s(\int_a^b p_s(t)dt) - \int_a^b (\alpha(t-t_s)p_s(t) + k(p_s(t), p_s^{*}(t))p_s(t))dt\} \tag{5.32}$$

$$F(p_s^{**}, p_s^{*}) = \int_a^b (\alpha(t-t_s)p_s(t) + k(p_s^{**}(t), p_s^{*}(t)))p_s^{**}(t)dt \tag{5.33}$$

3.6 Summary

In this study, the load rate and power load curve of various electrical appliances are obtained by analyzing the load characteristics of users. Different pricing mechanisms are adopted for different power demand users, so as to formulate a reasonable price strategy. Through the reasonable collection strategy of electricity charges, the contradiction between the supply and demand sides caused by the current fixed tariff mechanism dominated by the power sector can be solved. According to the expected load, the power company can accurately understand the real power demand of users, so as to timely arrange and adjust the power production, implement the power monitoring and dispatching from the perspective of global optimization, so as to improve the utilization rate of power resources and promote the sustainable development of power resources.

The real-time tariff collection strategy with dynamic reward and punishment mechanism proposed in this paper is a tariff collection strategy jointly formulated by both power supply and demand sides. It can induce users to use electricity according to their expectations by designing fair basic time of use price and dynamic reward and punishment mechanism based on load. Through the real-time price to induce and regulate the user's electricity consumption behavior, so as to effectively optimize and distribute the grid load. Therefore, this paper presents four optimal distribution principles and methods to determine the expected power consumption load.

Based on the real-time electricity tariff collection strategy with dynamic reward and punishment mechanism, the power sector can implement personalized charging for users. The difference of unit electricity cost mainly lies in the difference of basic TOU price and expected power load of users. It is always an incentive strategy for the company to adjust its own electricity tariff according to the actual demand of the power grid. From the perspective of long-term benefits, it can save resources, meet the demand and promote the rational use of electricity.

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Chapter 4

THE PROMOTION ANALYSIS OF POLICIES ON THE TECHNICAL SIDE OF DSM

CHAPTER FOUR: THE PROMOTION ANALYSIS OF POLICIES ON THE TECHNICAL SIDE OF DSM

4.1 Content

In the national level of energy consumption and carbon emissions policy analysis, there is less research involved in specific equipment energy efficiency improvement policy [1]. Based on Japan's equipment energy efficiency improvement policy, "Top Runner policy (TRP)", this paper analyzes the effect of policy implementation, and studies the energy and environmental benefits of equipment energy efficiency improvement.

The logic of the study is shown in Figure 4-1. Firstly, this paper studies the energy conservation and emission reduction potential of this policy related field in Japan through factor decomposition. Then, the energy-saving effect of TRP is identified by moving window and correlation analysis. Next, the correlation between specific equipment and corresponding fields is analyzed by stages. Finally, the rebound effect of CO_2 is analyzed to study the emission reduction effect of the policy.

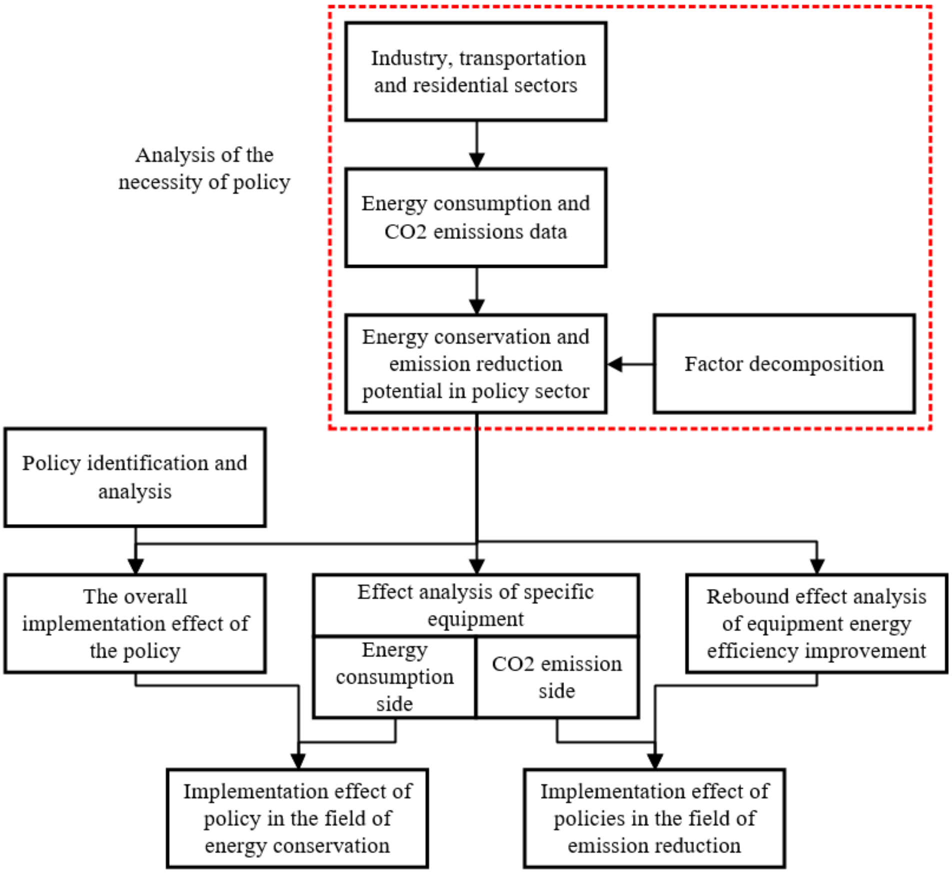


Figure 4-1. Research flow chart.

4.2. Methodology

4.2.1. Factor Decomposition

It is very meaningful to distinguish the influence of various factors, because in economic or other complex systems many variables are affected by multiple factors, that is, the change of variables is caused by multiple factors [2,3]. The objects of this paper are energy intensity (EI) and energy consumption CO_2 emission intensity (ECCEI).

$$\mathrm{EI} = \mathrm{Energy\ consuption/GDP} \tag{4-1}$$

$$\mathrm{ECCEI} = \mathrm{CO_2\ emission/Energy\ consuption} \tag{4-2}$$

This paper uses factor analysis method to analyze, which is to divide the change of variables into several parts and each factor corresponds one by one through mathematical method. Taking EI as an example, the definition formula of EI is as follows:

$$e_t = \frac{E_t}{G_t} \tag{4-3}$$

where e_t is the EI; E_t is the energy consumption during the t period; G_t is the GDP in the t period.

It is decomposed as follows:

$$e_t = \frac{E_t}{G_t} = \frac{\sum_i E_{it}}{\sum_i G_{it}} = \frac{\sum_i e_{it} G_{it}}{\sum_i G_{it}} = \sum_i e_{it} \frac{G_{it}}{\sum_i G_{it}} = \sum_i e_{it} p_{it} \tag{4-4}$$

where E_{it} refers the energy consumption of the i industry in the t time period; e_{it} refers the EI of the i industry in the t time period; G_{it} refers the EI of the i industry in the t time period; p_{it} refers the GDP ratio of the i industry in the t time period.

In the process of factor analysis, the value in a certain time period needs to be used as a comparison. If t = 0, the difference between the other time periods and their EI is:

$$\Delta e = e_t - e_0 = \sum_i e_{it} p_{it} - \sum_i e_{i0} p_{i0} \tag{4-5}$$

4.2.2. Moving Windows and Correlation Analysis

The combination of moving window and correlation analysis can effectively identify the policy and analyze the impact of policy implementation. C_i^t is defined as each moving window, where t is different starting time, i is different energy consumption types (refrigeration, heating, domestic hot water, lighting, etc.), and the size of each moving window is s [4].

The main method of correlation analysis is to draw correlation charts and calculate correlation coefficients [5]. There are three kinds of correlation coefficients that are often used, and among them, Pearson correlation coefficient is a measure of the degree of linear correlation, which is also commonly used at present [6]. In this paper, Pearson correlation coefficient will be calculated and analyzed by MATLAB.

Pearson's correlation coefficient is one of the important indicators to analyze the degree of correlation between variables, and it has been widely used in various fields.

$$\rho_{X,Y} = \frac{\mathrm{cov}(X,Y)}{\sigma_X\sigma_Y} = \frac{E((X-\mu_X)(Y-\mu_Y))}{\sigma_X\sigma_Y} = \frac{E(XY)-E(X)E(Y)}{\sqrt{E(X^2)-E^2(X)}\sqrt{E(Y^2)-E^2(Y)}} \tag{4-6}$$

The formula is defined as: The Pearson correlation coefficient (Px, y) of two continuous variables (X, Y) is equal to the covariance cov (X, Y) between them divided by the product of their respective standard deviations (σ_X, σ_Y). Coefficients are always between −1.0 and 1.0. Variables close to 0 are called uncorrelated, and those close to 1 or −1 are called strongly correlated. Usually, the correlation intensity of variables is judged by the following range of values: (1) very strong correlation: 0.8–1.0; (2) strong correlation: 0.6–0.8; (3) moderate correlation: 0.4–0.6; (4) weak correlation: 0.2–0.4; (5) very weak correlation or no correlation: 0.0–0.2 [7].

4.2.3. Life Cycle Rebound Effect

The use of high-efficiency energy technology can enable consumers to obtain the same amount of services with lower money expenditure, reduce the financial pressure of consumers, and may consume more energy. This phenomenon is called the "direct rebound effect" [8].

In this paper, the rebound effect of the carbon footprint (REC) is used to calculate the rebound effect. REC is defined as:

$$REC = \frac{(C_0 - C_1) - (C_1 - C_1')}{(C_0 - C_1)} \times 100\% \tag{4-7}$$

where C_0 is the carbon footprint without energy efficiency improvement; C_1 is the carbon footprint with energy efficiency improvement; C_1' is the actual carbon footprint.

4.3. Research Objects and Analysis

4.3.1. Factor Decomposition of Energy Saving and Emission Reduction Potential

Firstly, through the factor decomposition of EI and ECCEI, the potential of energy conservation and emission reduction in different fields is analyzed. According to the national economic statistics of the Cabinet Office of Japan, the 1990–2017 GDP of different industries is obtained [9]. According to the comprehensive energy statistics of the Ministry of Economy, Trade and Industry of Japan, the energy consumption and carbon emissions of different industries from 1990 to 2017 are sorted out [10].

In addition to the primary and secondary industries (PI and SI), energy consumption and carbon emissions of the tertiary industry, transportation and residential are highly correlated. At the same time, the calculation standard of GDP in the field of residential is different from that in other fields, and the energy consumption generated by residential will increase the GDP of the tertiary industry through payment. Residents' consumption can drive the increase in the GDP and energy consumption of the tertiary industry, and the increase in GDP through the tertiary industry will be returned to the residents in the form of wages. At the same time, the increase in the GDP of the tertiary industry and residents represents an increase in demand for transportation, which drives the growth of GDP and energy consumption in the transportation sector. Therefore, the energy consumption and carbon emissions of the tertiary industry, transportation and residential (TTR) are combined to analyze the factors. Figures 2 and 3 show the factor decomposition results of EI and energy consumption CO_2 emission intensity ECCEI. The structure and efficiency in Figures 4-2 and 4-3 are the structure factor and efficiency factor in the factor decomposition model. The structure factor represents the increase in the overall structure, and the efficiency factor represents the increase in energy utilization efficiency, that is, the decrease in unit energy consumption. Therefore, when the structure factor is negatively correlated with EI and ECCEI, it means that the increase of the structure ratio has led to the decrease of EI and ECCEI, which has a positive effect. When the efficiency factor is positively correlated with EI and ECCEI, it means that the decrease in unit energy consumption has led to the decrease in EI and ECCEI, which has a positive effect.

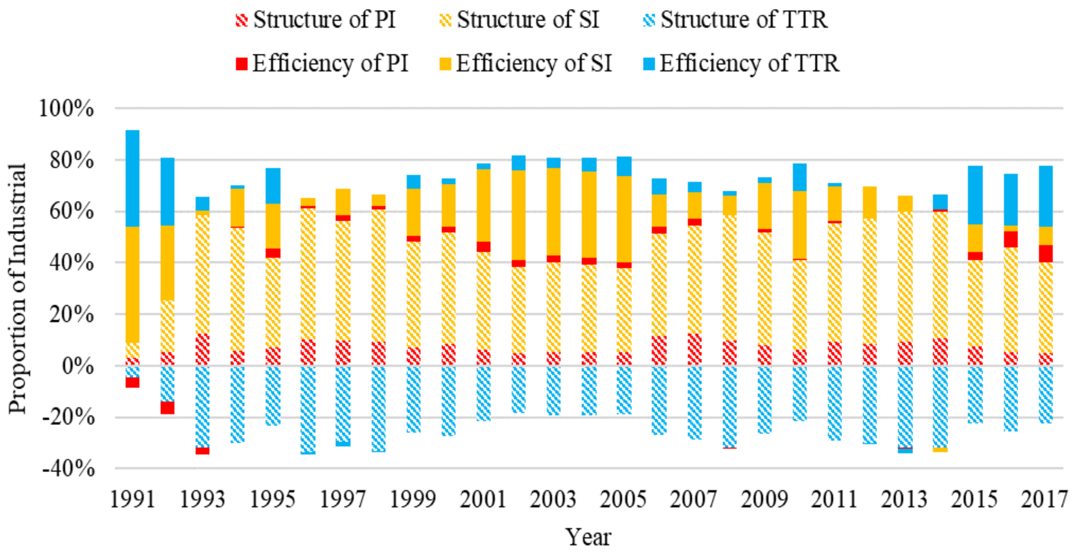


Figure 4-2. The proportion of structural factors and efficiency factors of energy intensity (EI).

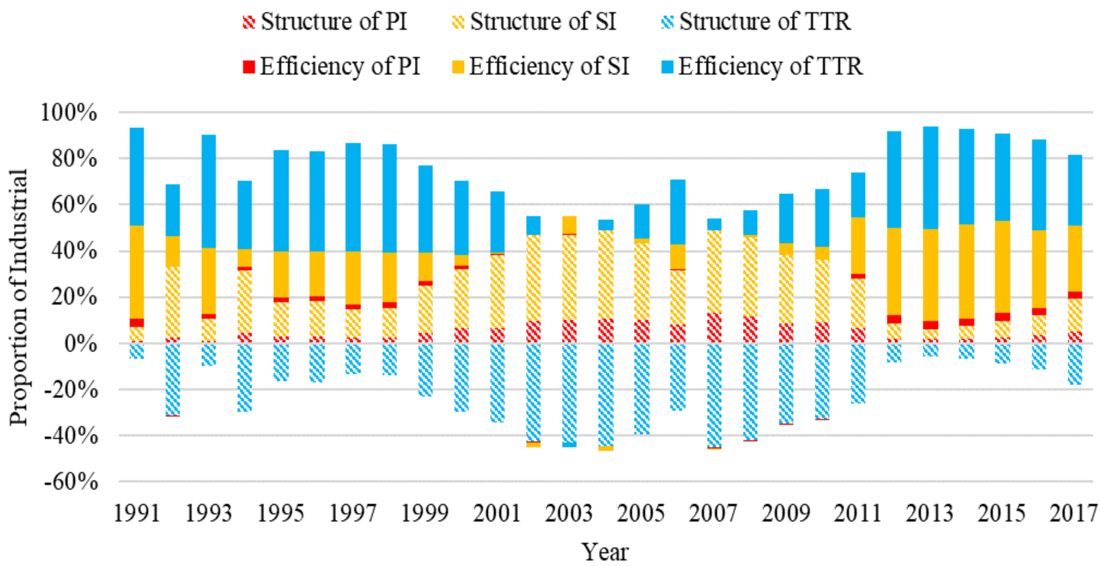


Figure 4-3. The proportion of structural factors and efficiency factors of energy consumption CO_2 emission intensity (ECCEI).

In the aspect of energy saving, the structure change of SI and TTR has obvious influence. The decrease of SI proportion and the increase of TTR will cause the decrease of overall EI. In terms of emission reduction, the structure change and efficiency change of TTR have obvious influence. The increase of TTR proportion and the decrease of ECCEI will cause the decrease of ECCEI.

It can be seen that both the increase in the proportion of TTR and the improvement of its own energy and environment have a significant impact on Japan's overall energy consumption and carbon reduction. This shows that TTR is the core of the field of energy conservation and environmental protection in Japan. Therefore, Japan has launched a series of energy conservation and environmental protection laws to promote the energy efficiency and environmental protection of TTR. In addition to similar policies in other countries, such as construction, residential energy consumption and promotion of distributed energy system, Japan has also launched equipment energy efficiency improvement policy (Top Runner policy, TRP) to promote the improvement of equipment energy utilization efficiency through equipment assessment. This study will make a detailed analysis on the implementation effect of this policy.

4.3.2. Identification of Top Runner Policy (TRP) and Analysis of Its Influence Lag

4.3.2.1. Overview of TRP

The TRP, combined with the energy consumption statistics of the initial assessment year of the equipment and the energy efficiency decline in the past few years, sets the energy efficiency decline target within the next 5 to 10. The targets of the policy are various energy equipment for the TTR, including passenger cars, trucks, household air conditioners, business air conditioners, fluorescent lighting, etc. Figure 4-4 shows the starting time of the assessment of different equipment.

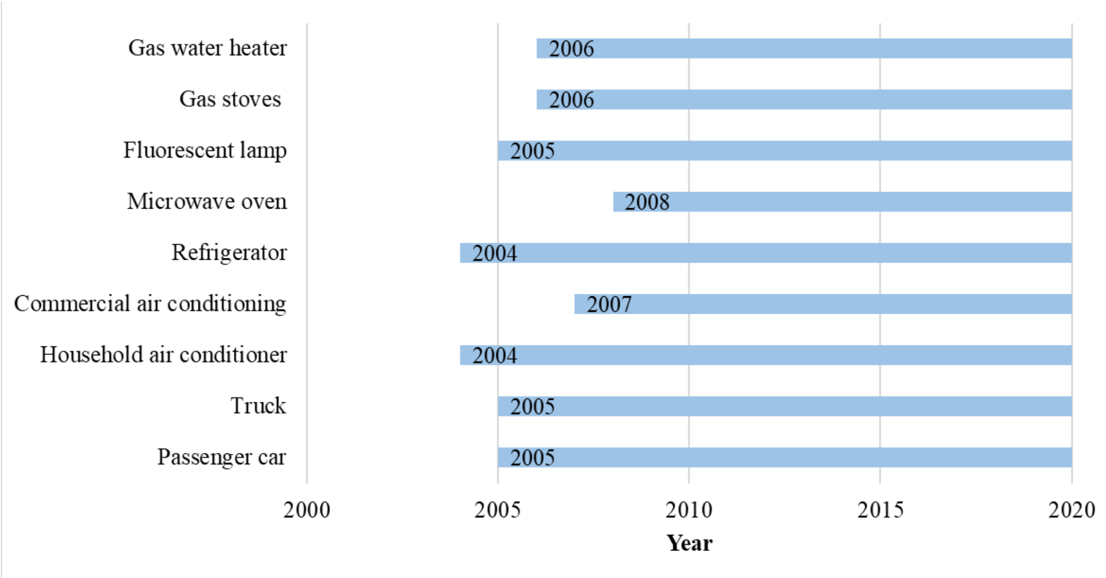


Figure 4-4. Assessment starting year of different equipment.

Most of the equipment energy efficiency assessment started from 2004–2005. From the statistical report of the system, most of the equipment has completed or exceeded the energy-saving target, and the energy efficiency of the equipment has been improved [11]. However, this efficiency improvement requires an in-depth analysis of the specific energy and environmental improvement in various fields of TTR.

4.3.2.2. Policy Identification and Impact Lag Analysis

(1) Policy effect identification in different energy consumption types

Through the statistical data of Japan's Ministry of resources and energy, the Institute of Energy Economics, the Ministry of General Affairs and other government departments, different types of energy in TTR are obtained. The tertiary industry and residential are divided into six aspects, including: (1) Refrigeration; (2) heating; (3) hot water; (4) kitchen; (5) lighting, power and others; (6) all energy consumption. Transportation is divided into tourism and freight. Since the new statistical method used in 1990 is obviously different from the data before 1989, different energy consumption data from 1990 to 2017 are used for analysis. The energy consumption data for the three areas of TTR as the basis of analysis are shown in Figure 4-5.

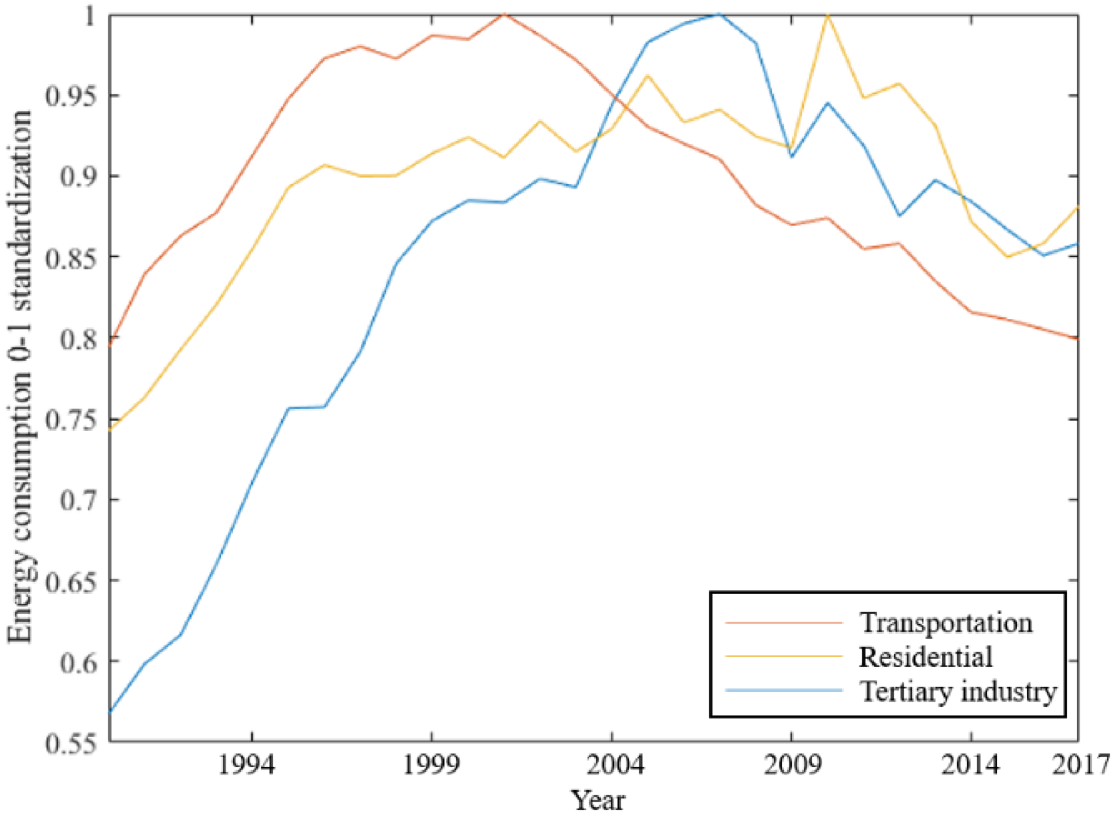


Figure 4-5. The 0–1 standardization of energy consumption in tertiary industry, transportation and residential.

In order to avoid the uncertainty of the correlation coefficient obtained by moving the window, it is necessary to expand the window size as much as possible [12]. Although the extended window cannot analyze the fast fluctuation, it can make the recognition effect more obvious. Considering that the implementation of the TRP is divided into different stages according to 5 to 10 years, the size of the window here is set as 10 years. The total energy consumption and different types of unit energy consumption of TTR are divided into moving windows. Then, the policy is identified by correlation analysis. Then, the policy identification results are shown in Figures 4-6, A1 and A2. (Take the tertiary industry as an example to explain)

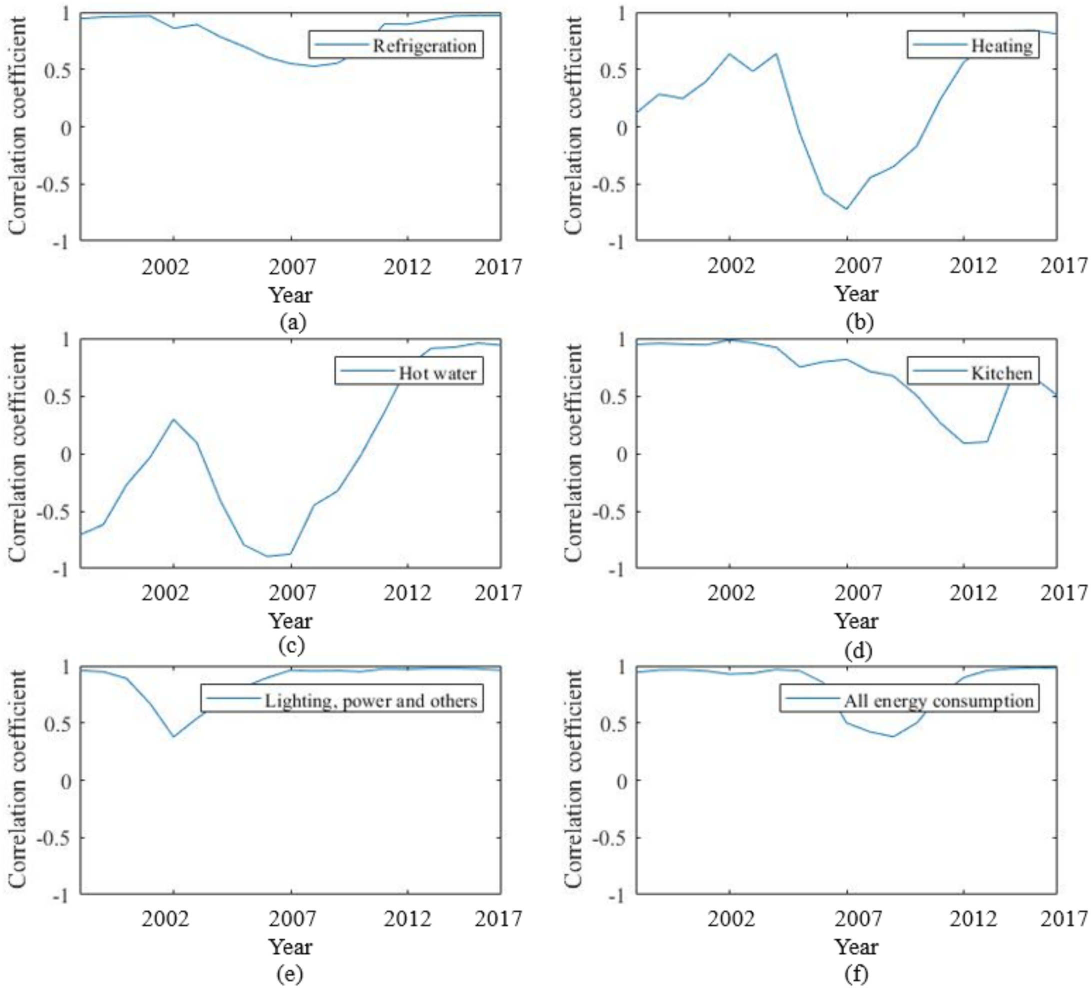


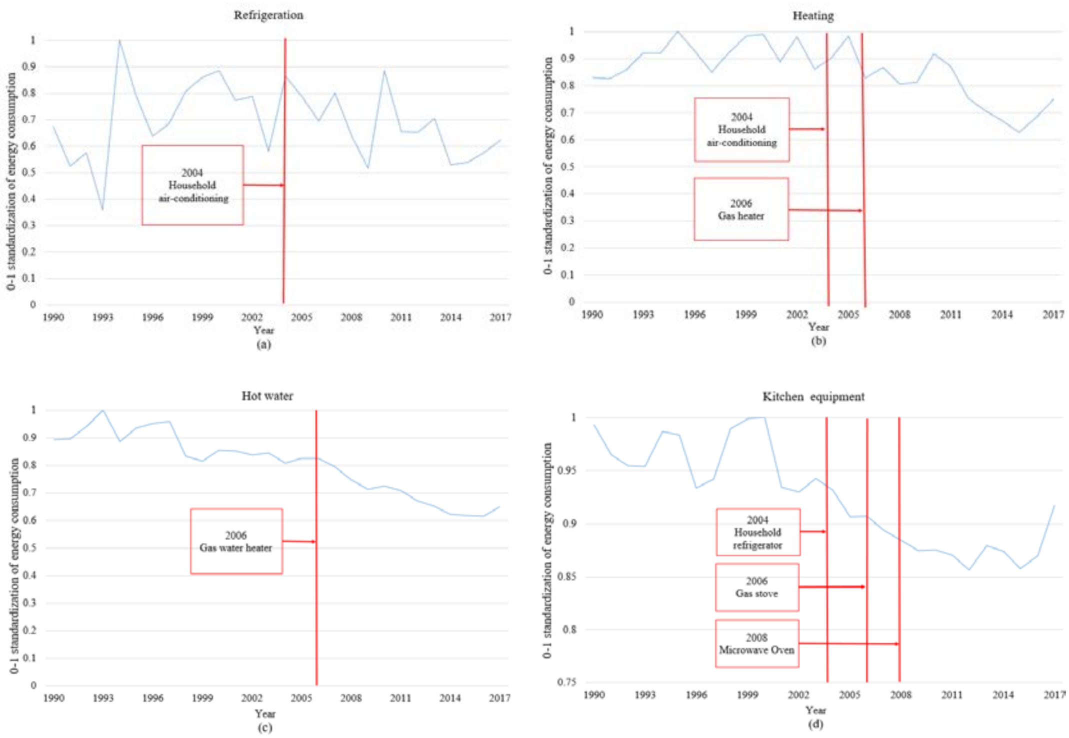
Figure 4-6. The policy identification results of the tertiary industry ((a) Refrigeration; (b) Heating;(c) Hot water;(d) Kitchen;(e) Lighting, power and others;(f) All energy consumption).

Taking tertiary industry as an example to explain, except for domestic hot water, other energy types showed strong positive correlation with tertiary industry at the beginning. Then all types of energy fluctuate in the direction of negative correlation, which is due to the different beginning time of energy efficiency improvement. Finally, for all types of energy efficiency have entered the stage of improvement, the overall energy consumption of the tertiary industry also began to decline, and the correlation returned to a strong positive correlation. Among them, the correlation between refrigeration and the overall unit energy consumption change trend is the most similar, indicating that the effect of energy efficiency improvement in refrigeration is the most obvious. At the same time, the overall unit energy consumption correlation fluctuated in 2005, which is completely consistent with the implementation time of the policy, indicating that the effect of the policy on energy consumption reduction is very obvious.

Compared with the situation in Figures A1 and A2, it can be seen that the energy efficiency improvement research in transportation and housing has been paid attention to at an earlier stage [12], and the energy consumption has decreased before the promotion of the policy. Therefore, although there are obvious correlation changes, but the time volatility is large. Only tourism, household refrigeration, lighting and power are consistent with the implementation time of the policy.

(2) The independence and hysteresis of policy analysis

Although the policy identification shows that the policy has an obvious effect on the reduction of energy consumption, the identification effect is not ideal in some energy consumption types which started earlier. Therefore, through the comparison of different types of unit energy consumption and the corresponding policy promotion time, this paper studies the impact of policies on energy consumption decline rate and the lag of promotion effect. The comparative results of the tertiary industry are shown in Figure 4-7. The comparison results of transportation and residential are shown in Figures A3 and A4.



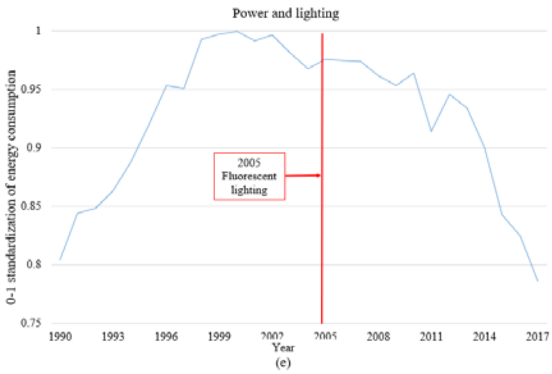


Figure 4-7. Comparison of different types of energy consumption and the starting time of corresponding policies in tertiary industry((a) Refrigeration;(b) Hot water; (c) Heating;(d) Kitchen equipment;(e) Power and lighting).

In the fields of refrigeration, kitchen, lighting and power, unit energy consumption peaked and began to decline 1–2 years after the implementation of the policy. In terms of heating and domestic hot water, unit energy consumption decreased before the implementation of the policy, but the implementation of the policy increased the rate of decline and brought more obvious energy-saving effect. According to Figures A3 and A4, due to the earlier attention paid to the transportation and residential sectors, the unit energy consumption has been in the decline stage for a long time. However, the implementation of the policy can accelerate the decline rate.

Therefore, it is considered that the TRP can effectively reduce the energy consumption of TTR. Next, the impact of specific equipment will be analyzed, and a comprehensive evaluation combined with carbon emissions will be conducted

4.4. Impact Analysis of Equipment Energy Efficiency Improvement

According to the self-statistics of different equipment industries and the combing of some government departments, the statistics of equipment energy efficiency changes up to 2014 (ten years after the implementation of the policy) are obtained, including: Commercial air conditioner, commercial refrigerator, residential air conditioner, residential refrigerator, spherical light, fluorescent light, gas stove, microwave oven, gas water heater, electric water heater, passenger car, minibus, bus and truck. The average energy consumption of these equipment in one year will be analyzed with energy consumption and carbon emissions in the corresponding fields. In order to analyze the impact of the policy more clearly, the correlation is divided into stages 1990–2014, 2000–2014 and 2005–2014. The results of the three stages will be compared to analyze the effect of policy implementation.

(1) Tertiary industry

The correlation between equipment and the tertiary industry energy consumption and carbon emission at different stages is shown in Figures 4-8 and 4-9. The correlation between equipment and energy consumption showed a strong positive correlation in the 2005–2014 stage, especially in air conditioning, refrigeration and microwave ovens. In terms of carbon emissions, it is negatively correlated at the beginning, and turned to positive correlation in the 2005–2014 stage. In the tertiary industry, the improvement of equipment energy efficiency can significantly reduce energy consumption, but the effect on CO_2 emission reduction is weak. The correlation coefficient of energy consumption and the carbon emission of the tertiary industry is 0.9128, with strong correlation. However, as the energy consumption in the business field is mainly composed of gas, oil and electricity, the reduction of energy consumption mainly comes from the conversion of oil consumption to natural gas consumption, and the effect on CO_2 emission reduction is not obvious.

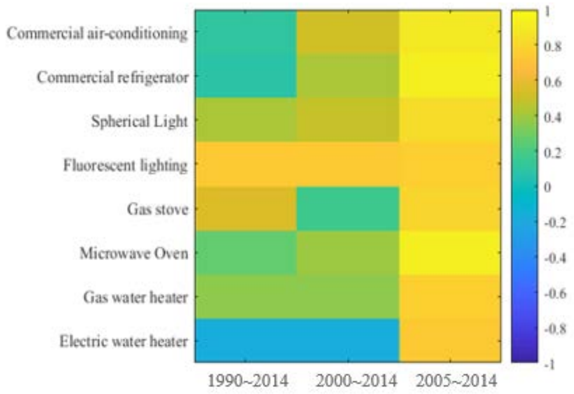


Figure 4-8. Correlation between equipment energy efficiency improvement and energy consumption of tertiary industry in different stages.

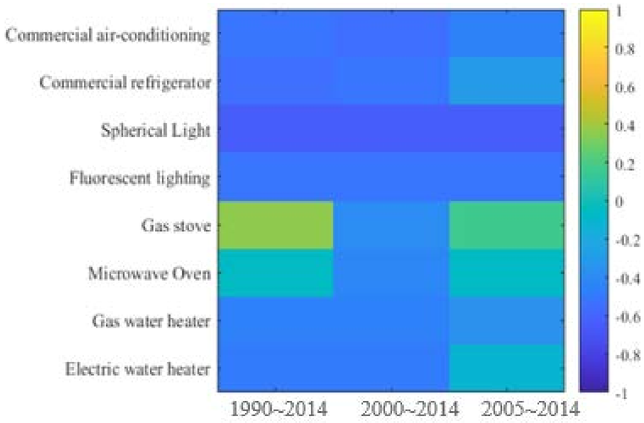
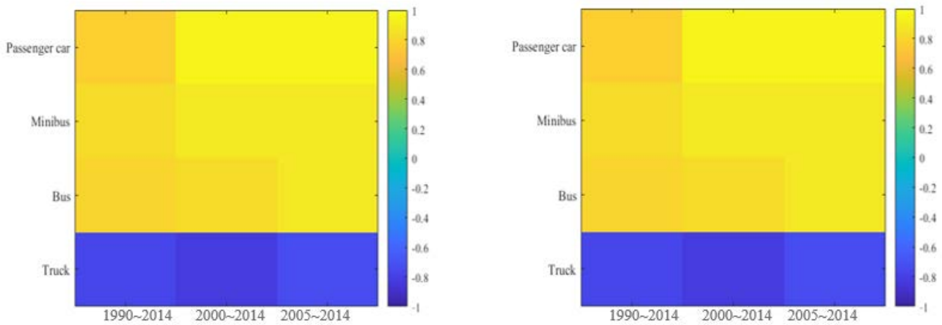


Figure 4-9. Correlation between equipment energy efficiency improvement and CO_2 emission of tertiary industry in different stages.

(2) Transportation

The correlation between equipment and transportation energy consumption and carbon emission at different stages is shown in Figure 4-10. Due to the increasing demand for trucks, more heavy-duty trucks with higher energy consumption have been introduced, resulting in the continuous improvement of the average energy consumption of trucks. In addition to trucks, other equipment has a strong positive correlation with energy consumption and CO_2 emissions from the beginning. However, there is still a positive improvement in the correlation in the 2005–2014 stage. Although affected by other energy-saving policies, the TRP still plays a certain role. At the same time, the analysis results of energy consumption and carbon emission in the field of transportation are similar, because the correlation coefficient of energy consumption and carbon emission in transportation field is 0.9957. The CO_2 emissions of energy used in the field of transportation are similar, and the change of energy consumption structure has little impact on carbon emissions, resulting in the energy-saving effect of equipment, which has a great effect on CO_2 emission.



(a) Equipment and energy consumption (b) Equipment and CO_2 emission

Figure 4-10. Correlation between equipment energy efficiency improvement, energy consumption and CO_2 emission of transportation in different stages ((a) with energy consumption and (b) with CO_2 emission).

(3) Residential

The correlation between equipment and residential energy consumption and carbon emission at different stages is shown in Figures 4-11 and 4-12. It can be seen that the improvement of equipment energy utilization efficiency has a positive correlation with the decrease of household energy consumption, and the increase in 2005–2014 stage. But in terms of CO_2 emissions, it has been in a negative correlation state. It shows that the improvement of energy utilization efficiency of equipment in the residential field cannot contribute to the emission reduction. Even, due to the improvement of living standards of residents and the popularization of electrification, CO_2 emissions show an upward trend.

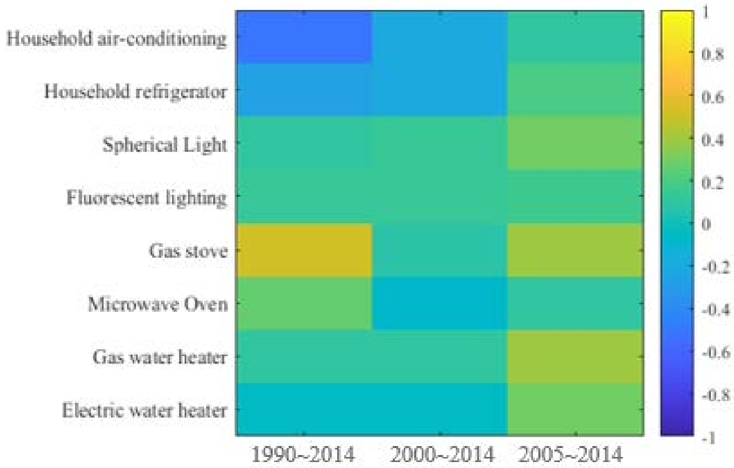


Figure 4-11. Correlation between equipment energy efficiency improvement and energy consumption of residential in different stages.

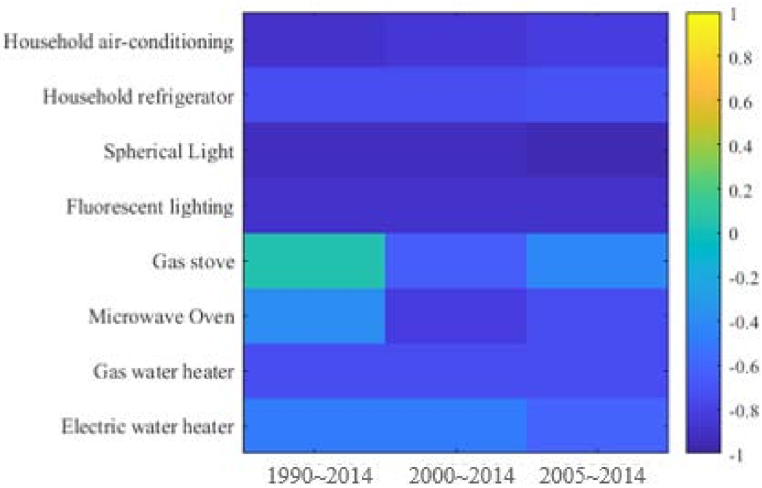


Figure 4-12. Correlation between equipment energy efficiency improvement and CO_2 emission of residential in different stages.

According to the above analysis results of the equipment, the TRP has played a positive role in reducing energy consumption in the three areas of TTR, but there are differences in the results of CO_2 emission reduction. In the field of transportation, the effect of emission reduction is very obvious. In the tertiary industry, the effect of carbon dioxide emission reduction shows a positive trend, but in the residential sector, the impact on CO_2 emission reduction is not significant. Therefore, the CO_2 rebound effect of equipment will be analyzed to study the actual effect of equipment energy efficiency improvement brought by the policy.

4.5. CO_2 Rebound Effect Analysis

Referring to the building energy efficiency evaluation system of Japan and other countries [13], it can be seen that the energy equipment of the tertiary industry and residential buildings can be divided into two types: (1) Heating, ventilation and air conditioning; (2) lighting and power. Therefore, air conditioning and lighting are chosen to represent these two types of energy equipment. Passenger cars are chosen to represent energy equipment in the transportation sector. The research takes this three equipment as representatives to analyze the rebound effect of production, use and scrapping in the life cycle stage. Since the energy consumption structure of the three equipment in the production and scrapping stage has little change, the energy consumption and carbon emission in the whole life cycle stage are basically linear correlation, so the rebound effect of carbon emissions is explained. The carbon emission parameters of the equipment life cycle are shown in Table 4-1 below.

Table 4-1. The carbon emission parameters of the equipment life cycle [9, 14-16].

Type	Manufacture and Transportation($kgCO_2$)	The End of Use ($kgCO_2$)	Service Life (Year)	Use	
				Energy Type	Carbon Emission
Spherical light	11.525	0.89	7.5	electricity	0.455 $kgCO_2$/kWh
Household air-conditioning	147	10	15.7	electricity	0.455 kgCO2/kWh
Passenger car	6000	300	13	gasoline	2.3 $kgCO_2$/L

According to the policy stages, the starting years of lighting, air conditioning and passenger cars are 2005, 2004 and 2005, respectively, and the average rebound effect of the carbon footprint (REC) within 10 years from the beginning of the policy is calculated. Three types of REC calculation are carried out, which are (1) use stage; (2) whole stage; (3) life cycle. The whole stage refers to the CO_2 emission in the whole stage of production, use and end of use in each year, and compares with the theoretical CO_2 emission reduction caused by the energy efficiency improvement of the equipment. Compared with REC which only considers the use stage, the impact of annual production and end of use is increased. The whole life cycle is to analyze the long-term CO_2 emission impact based on the whole stage and considering the service life of the equipment. The REC comparison of lighting, air conditioning and passenger cars in three stages is shown in Table 4-2.

Table 4-2. The rebound effect of lighting, air conditioning and passenger cars in three stages.

Type	Rebound Effect of the Carbon Footprint (REC)			
	Use Stage	Whole Stage	Life Cycle	Volatility in Life Cycle (Variance)
Spherical light	0.150	0.167	0.152	0.016
Household air-conditioning	1.144	1.161	1.145	0.028
Passenger car	0.414	1.235	0.448	2.182

It can be seen that the rebound effect in the operation stage is very close to that in the whole life cycle. In these two stages, air conditioning REC is the highest, which represents the best CO_2 emission reduction effect brought by the improvement of air conditioning energy efficiency. The REC of fluorescent lamp is very small, and there is no benefit of energy saving and emission reduction. Among them, the carbon dioxide emissions of passenger cars in the manufacturing and scrap recovery stage account for a high proportion, which leads to the strong volatility of REC. This also results in the best energy-saving and emission reduction effect of passenger cars in the whole stage.

According to the results of the rebound effect during the implementation of the policy, the energy efficiency improvement of passenger cars can bring the largest short-term CO_2 emission reduction. From the perspective of the whole life cycle, the energy efficiency improvement of air conditioning system has the most obvious emission reduction effect. It shows that although the emission reduction effect of the TRP is only obvious in the field of transportation, as the promotion rate of electrification rate tends to be slow, the emission reduction effect of the policy will be more obvious from the perspective of the whole life.

4.6. Summary

The policy of improving energy efficiency of equipment can help to offset the increase in energy consumption and CO_2 emissions as demand increases. However, the implementation of a variety of energy conservation and emission reduction policies at the same time often results in the failure to effectively analyze the effect of single policy. In this paper, the identification and comprehensive evaluation method of equipment energy efficiency improvement policy (EEEIP) was proposed, and the Japan's Top Runner policy (TRP) was taken as an example to verify. Firstly, the potential of energy conservation and emission reduction in policy-related fields is analyzed by factor decomposition model. The results show that the increase of the proportion of energy consumption and energy utilization efficiency of tertiary industry, transportation and residential has a positive significance for the overall energy consumption and CO_2 emissions. Through the identification and effect analysis of TRP, the evaluation results are as follows.

(1) In terms of the overall effect of the policy, through moving window and correlation analysis, the effects of TRP in the tertiary industry, transportation and residential were identified and analyzed. Among them, the effect in the tertiary industry was the best. In the field of transportation and family, although affected by other earlier energy-saving policies, it still had a certain effect.

(2) In terms of specific equipment, the energy and environmental impacts of the specific equipment involved in the TRP were analyzed through correlation analysis in different stages. For energy saving, most of the equipment had a positive impact, especially business air conditioning, business cold storage, microwave oven and passenger cars. For emission reduction, the tertiary industry and transportation had a positive impact, but the effect in the family area was not obvious.

(3) In terms of short-term and long-term impacts, the short-term and long-term rebound effects of CO_2 emissions were analyzed from use stage, whole stage and life cycle perspectives. The REC of fluorescent lamp lighting was only 0.15 in both short-term and long-term, and the effect of energy-saving and emission reduction was basically offset. Air conditioning and passenger cars had better short-term effect, and the index REC of rebound effect was 1.16 and 1.24, respectively. For long-term effect, air conditioning had the best effect. Therefore, although the effect of TRP in the field of emission reduction was not obvious at present, the effect of equipment will gradually appear over time.

This paper took Japan's TRP as an example to verify the identification and evaluation methods of equipment energy efficiency improvement policy, involving two aspects of energy consumption and CO_2 emissions, as well as two dimensions of short-term and long-term, which has high reference value for the evaluation of equipment energy efficiency improvement policies. However, factors such as the early introduction of energy-saving policies for some equipment and the increase in electrification rates still affected the analysis results. Therefore, there is still room for further improvement in the study of rebound effects.

Appendix

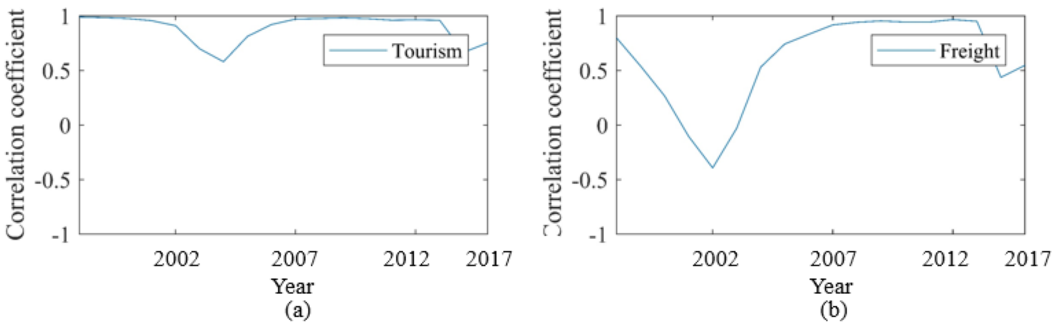


Figure A1. The policy identification results of transportation ((a) tourism and (b) freight).

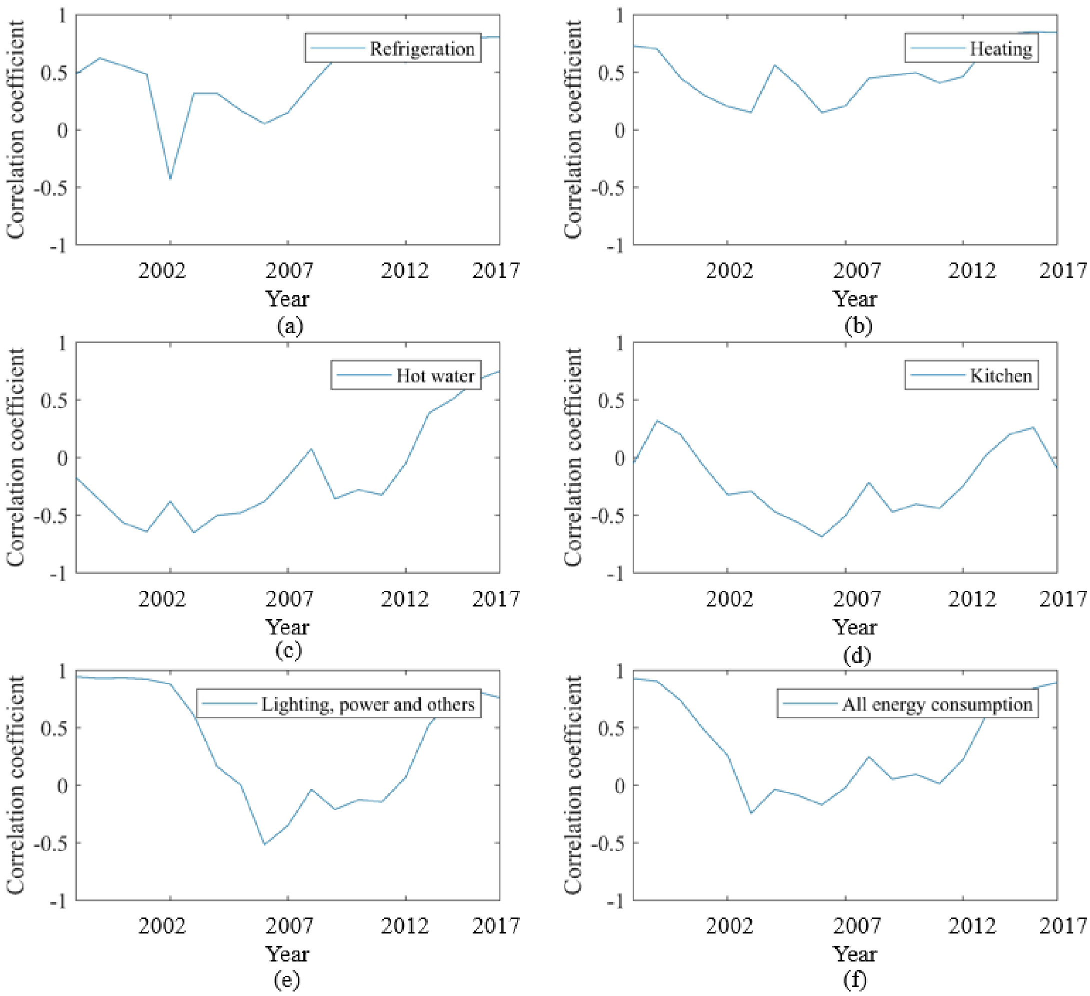


Figure A2. The policy identification results of residential (refrigeration, heating, hot water, kitchen, lighting, power and others)((a) Refrigeration;(b) Heating;(c) Hot water;(d) Kitchen;(e) Lighting, power and others;(f) All energy consumption).

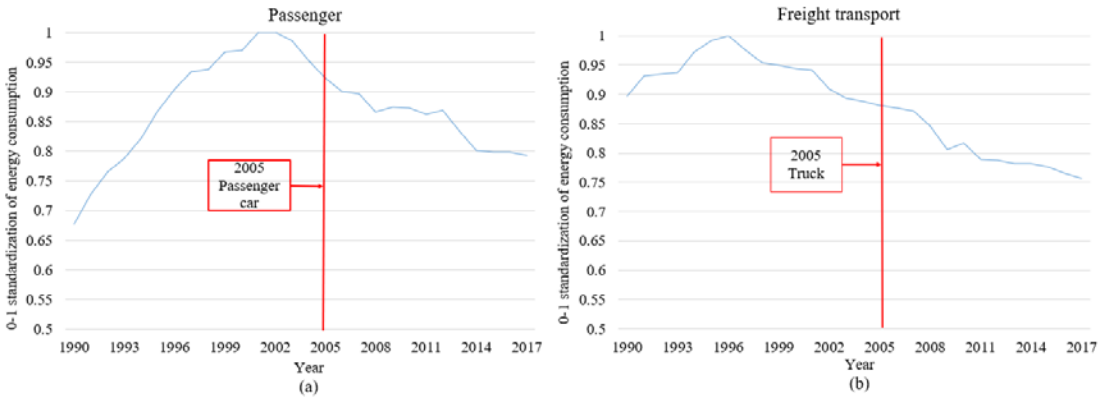
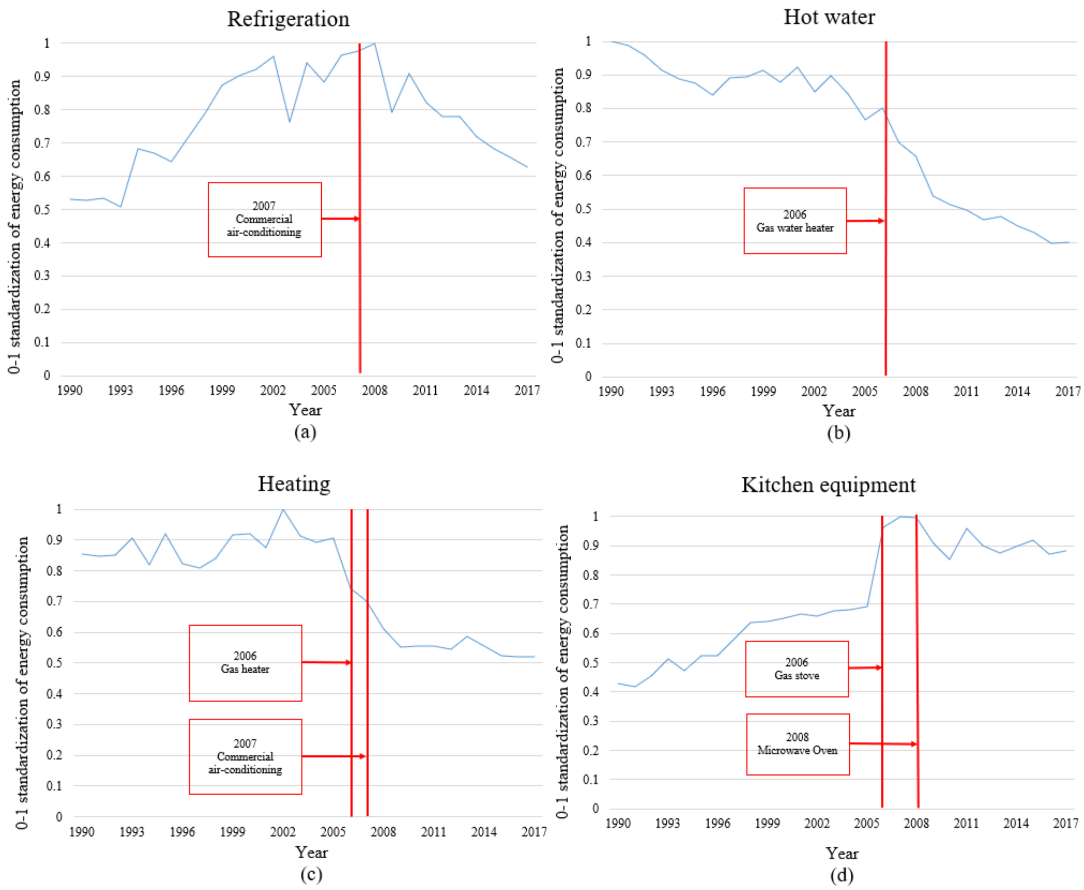
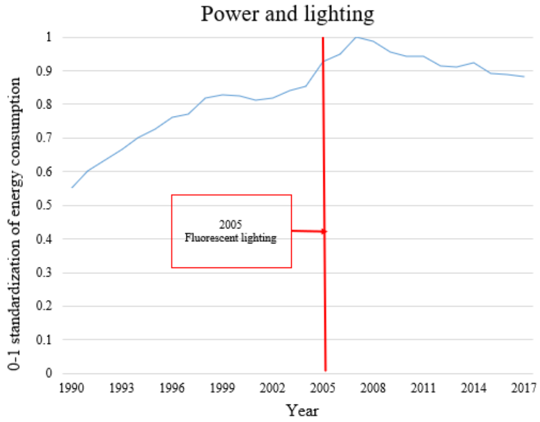


Figure A3. Comparison of different types of energy consumption and the starting time of corresponding policies in transportation ((a) Passenger and (b) Freight transport).





(e)

Figure A4. Comparison of different types of energy consumption and the starting time of corresponding policies in residential ((a) Refrigeration;(b) Hot water; (c) Heating;(d) Kitchen equipment;(e) Power and lighting).

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Chapter 5

THE EFFECT ANALYSIS OF ELECTRICITY PRICE ON THE TECHNICAL SIDE OF DSM

CHAPTER FIVE: THE EFFECT ANALYSIS OF ELECTRICITY PRICE ON THE TECHNICAL SIDE OF DSM

5.1 Content

In order to study the effect of DSM economic side measures, this study firstly studied the retail and wholesale electricity prices of Japanese electricity market through correlation analysis and moving window prediction. The relationship between supply and demand, power structure and objective climate and time environment was analyzed. Then it analyzed the specific effect of the combination of equipment energy efficiency improvement and load adjustment in different electricity price modes. Finally, the adaptability of different electricity price models to technical side means was studied.

5.2 Correlation analysis of long term average electricity price

With the amendment of the electricity business act of 2013, Japan's electricity retail market was fully opened in 2016. By 2020, the top 10 power companies will realize the separation of power generation, transmission and sales. As shown in Figure 5-1, the proportion of transaction volume of wholesale market in total electricity demand in 2016-2018 is shown. Although the price fluctuation in Japan's wholesale electricity market has been able to change every half an hour, the price change on the supply side is still unable to be reflected in the retail price. This is because the price mechanism of electricity retail market is still lagging behind, maintaining the tradition of step price and time of use price. However, with the development of power market, the real-time price and the retail market in which consumers participate will come [1]. It can also be seen from figure 5-1 that the wholesale market is having a huge impact on Japan's electricity market. Therefore, it is necessary to analyze the correlation between retail and wholesale electricity prices in Japan in recent years.

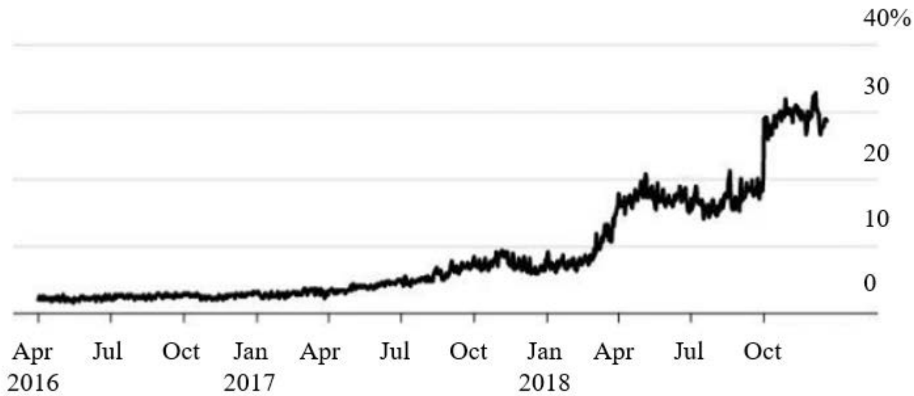


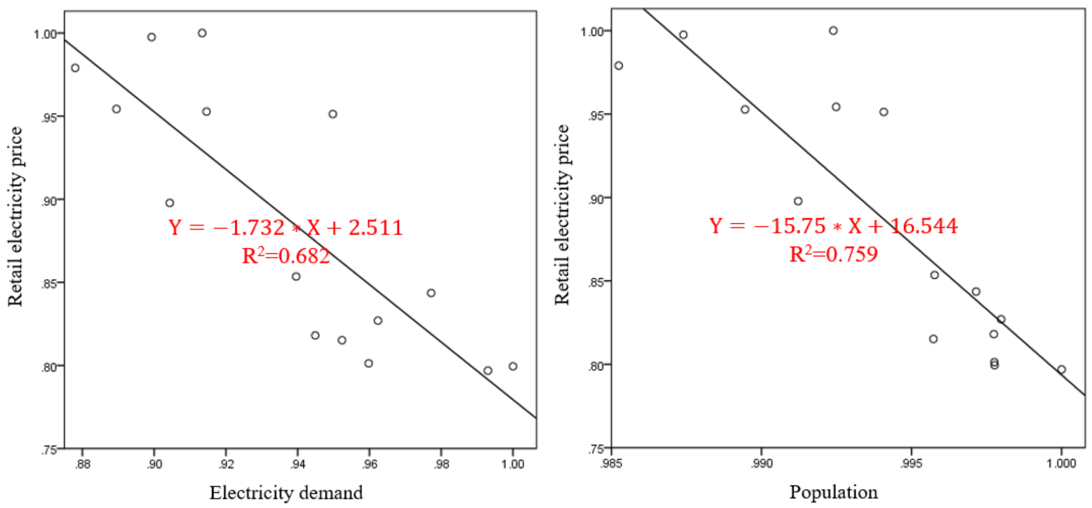
Figure 5-1 Trend of the proportion of wholesale electricity over time

5.2.1 Retail electricity price

Taking Kyushu as an example, through the statistical data of Kyushu Electric Power Company, the annual average retail electricity price, power demand, power structure, per kilowatt hour cost and the proportion of wholesale purchased electricity in Kyushu are obtained. In addition, through the relevant statistics of the Japanese government, the annual population and GDP changes of Japan are sorted out [2,3]. Through curve fitting and correlation analysis, the results as shown in Table 5-1 are obtained. It can be seen that the total demand for electricity, population, electricity cost per kilowatt hour of coal-fired power plants and the proportion of thermal power generation have a high impact on retail prices. The fitting results of these four variables with retail electricity price are shown in Figure 5-2. At the same time, the proportion of wholesale procurement power is not high, but has a high degree of fitting, as shown in Figure 5-3.

Table 5-1 Fitting results and correlation analysis of retail price and power related parameters

Program	Fitting degree	Fitting function	Correlation coefficient	Significance level
Total electricity demand	0.682	linear	-0.826**	0.00
GDP	0.302	linear	0.549*	0.03
Population	0.759	linear	-0.871**	0.00
Coal cost per kilowatt hour	0.516	square	0.698**	0.00
Gas cost per kilowatt hour	0.319	linear	0.565*	0.03
Proportion of wholesale electricity	0.838	square	-0.404	0.14
Proportion of hydropower generation	0.358	linear	0.598*	0.02
Proportion of thermal power generation	0.628	square	0.714**	0.00
Proportion of nuclear power generation	0.532	cubic	-0.544*	0.04
Proportion of renewable power generation	0.359	linear	0.599*	0.02
**. The correlation was significant at 0.01 level (double tailed test)				
*. The correlation was significant at 0.05 level (double tailed test)				



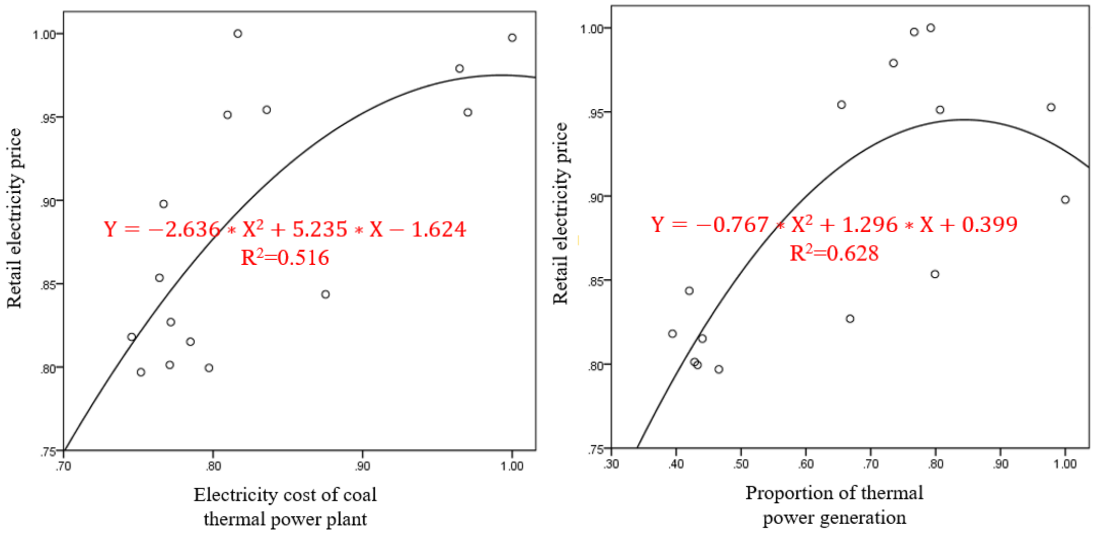


Figure 5-2 Fitting results of variables with high correlation（Electricity demand, Population, Electricity cost of coal thermal power plant, Proportion of thermal power generation）

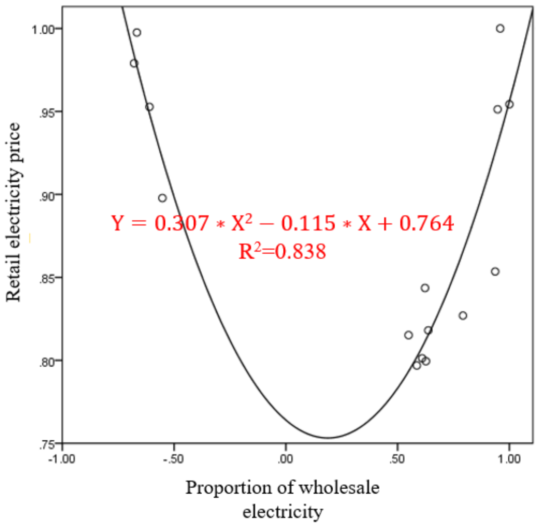


Figure 5-3 Fitting result of the proportion of wholesale electricity

Due to the nuclear leakage event in 2011, the supply of nuclear power plant decreased sharply, which can only be supplemented by thermal power generation, resulting in the fitting function of power cost per kilowatt hour of coal-fired power plant and the proportion of thermal power generation as quadratic function. At the same time, after the full opening of the power market in 2016, due to the participation of a large number of small power retailers, the overall balance of supply and demand of Kyushu power has changed from power procurement to power wholesale. It can be seen that there is a strong correlation between the wholesale electricity quantity and the retail electricity price after the Kyushu power is transferred to the wholesale stage.

5.2.2 Wholesale electricity price

Similar to the retail electricity price, according to the statistics of Japanese electricity trading market, the annual average wholesale electricity price change is obtained. Table 5-2 shows the fitting and correlation analysis results of wholesale electricity price and other variables. It can be seen that the proportion of electricity generated by gas and electricity is the highest in the electricity price of power plants (Figure 5-4). In addition, the proportion of wholesale electricity has a high correlation with the wholesale electricity price (Figure 5-5).

Table 5-2 Fitting results and correlation analysis of wholesale electricity price and power related parameters

Program	Fitting degree	Fitting function	Correlation coefficient	Significance level
Total electricity demand	0.169	square	0.18	0.52
GDP	0.245	square	-0.41	0.13
Population	0.045	linear	0.21	0.45
Coal cost per kilowatt hour	0.166	square	-0.26	0.35
Gas cost per kilowatt hour	0.506	linear	0.711**	0.00
Proportion of wholesale electricity	0.567	square	0.565*	0.03
Proportion of hydropower generation	0.197	square	-0.11	0.69
Proportion of thermal power generation	0.212	square	0.28	0.31
Proportion of nuclear power generation	0.690	square	-0.727**	0.00
Proportion of renewable power generation	0.223	cubic	-0.44	0.10
**. The correlation was significant at 0.01 level (double tailed test) *. The correlation was significant at 0.05 level (double tailed test)				

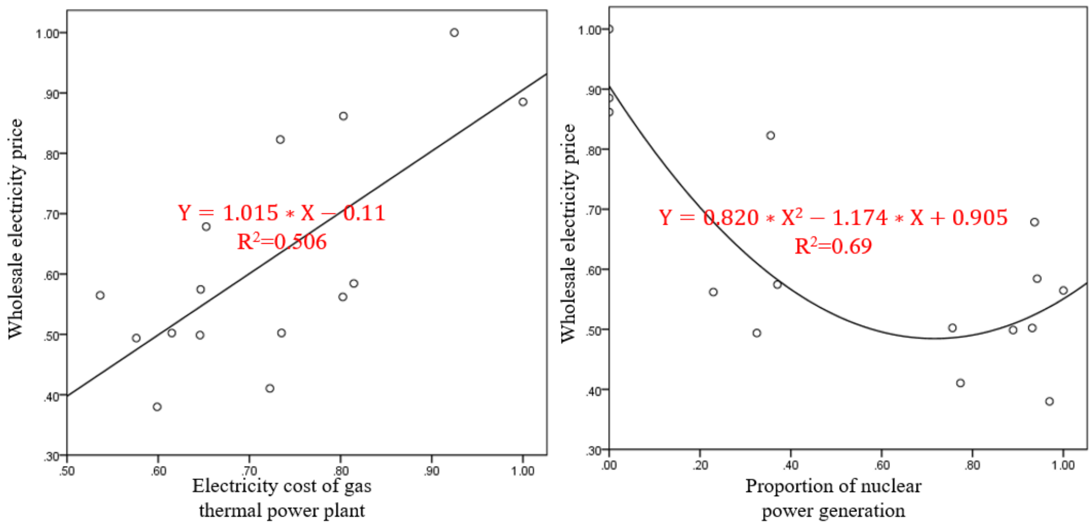


Figure 5-4 Fitting results of variables with high correlation（Electricity cost of gas thermal power plant, Proportion of nuclear power generation）

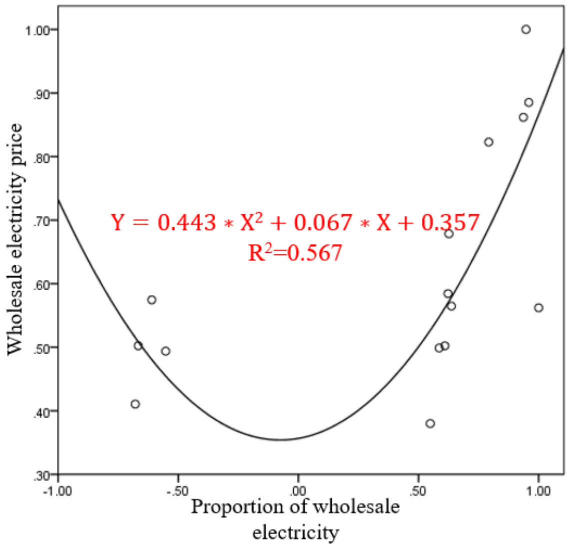


Figure 5-5 Fitting result of the proportion of wholesale electricity

Combined with the correlation analysis results of wholesale electricity and retail electricity price, although wholesale electricity price mainly affects suppliers, from the current actual effect, it has little impact on retail electricity price. But in the long run, especially after the full opening of retail market and the implementation of real-time pricing strategy, wholesale electricity price will have a great impact on retail price. Therefore, for the demand side, due to the lack of hourly retail electricity price data, it is also of high value for the short-term correlation analysis and prediction of wholesale electricity prices.

5.3 Correlation analysis and forecast of short term electricity price

5.3.1 Correlation analysis

Table 5-2 analyzes the impact of wholesale electricity price on power generation and power supply enterprises. For short-term electricity price, in addition to the above factors, climate factors and time factors will also have a significant impact on electricity prices. Therefore, through the data collected by Fukuoka meteorological station in Kyushu Prefecture, the variables used for correlation analysis are sorted into three categories: power supply and demand relationship and objective data (climate and time). The electricity price and related data are collected from April 1, 2016 to September 30, 2020. The correlation analysis is shown in table 5-3.

Table 5-3 Correlation analysis of wholesale electricity price and power related parameters

Program	Correlation coefficient	Significance level
Total electricity demand	0.624**	0.000
Proportion of hydropower generation	-0.122**	0.000
Proportion of thermal power generation	0.313**	0.000
Proportion of nuclear power generation	-0.355**	0.000
Proportion of renewable power generation	-0.235**	0.000
Wind speed	0.087**	0.000
Radiation	-0.084**	0.000
Dry bulb temperature	-0.090**	0.000
Relative humidity	-0.056**	0.000
Sunshine time	-0.054**	0.000
Hours per day	0.243**	0.000
Month	0.011*	0.028
Day per week	-0.005	0.312
**. The correlation was significant at 0.01 level (double tailed test) *. The correlation was significant at 0.05 level (double tailed test)		

It can be seen that, except for months and weeks, the other data have a high level of impact significance with wholesale electricity prices, but only the correlation coefficient of demand is higher. Next, we will further study the influence factors of wholesale electricity price through electricity price forecast.

5.3.2 Price forecasting based on levenbreg Marquardt back propagation (LMBP)

Different variables are used to forecast the electricity price [4], and the data is divided into three parts: training data, validation data and test data. According to the quarterly division of power companies, the test data is the latest statistical data from April 1, 2020 to September 30, 2020. Training data and validation data were divided according to the ratio of 8:2. The forecast results are shown in table 5-4. It can be seen that only the forecast accuracy of demand can reach about 65% (Fig. 5-6), which has certain practical application value (see figures B-1 and B-2 in the appendix for data and error distribution), and the other forecasting accuracy is low. This is consistent with the results in table 5-3.

Table 5-4 Forecasting results of wholesale electricity price by power related parameters

	Fitting Degree		
Program	Training Data	Validation data	Testing Data
Total electricity demand	0.633	0.661	0.653
Proportion of hydropower generation	0.197	0.210	0.214
Proportion of thermal power generation	0.347	0.367	0.362
Proportion of nuclear power generation	0.499	0.525	0.510
Proportion of renewable power generation	0.350	0.358	0.361
Wind speed	0.100	0.127	0.091
Radiation	0.188	0.220	0.212
Dry bulb temperature	0.387	0.415	0.413
Relative humidity	0.135	0.163	0.138
Sunshine time	0.100	0.111	0.111
Hours per day	0.391	0.394	0.394
Month	0.259	0.285	0.282
Day per week	0.010	0.002	0.020

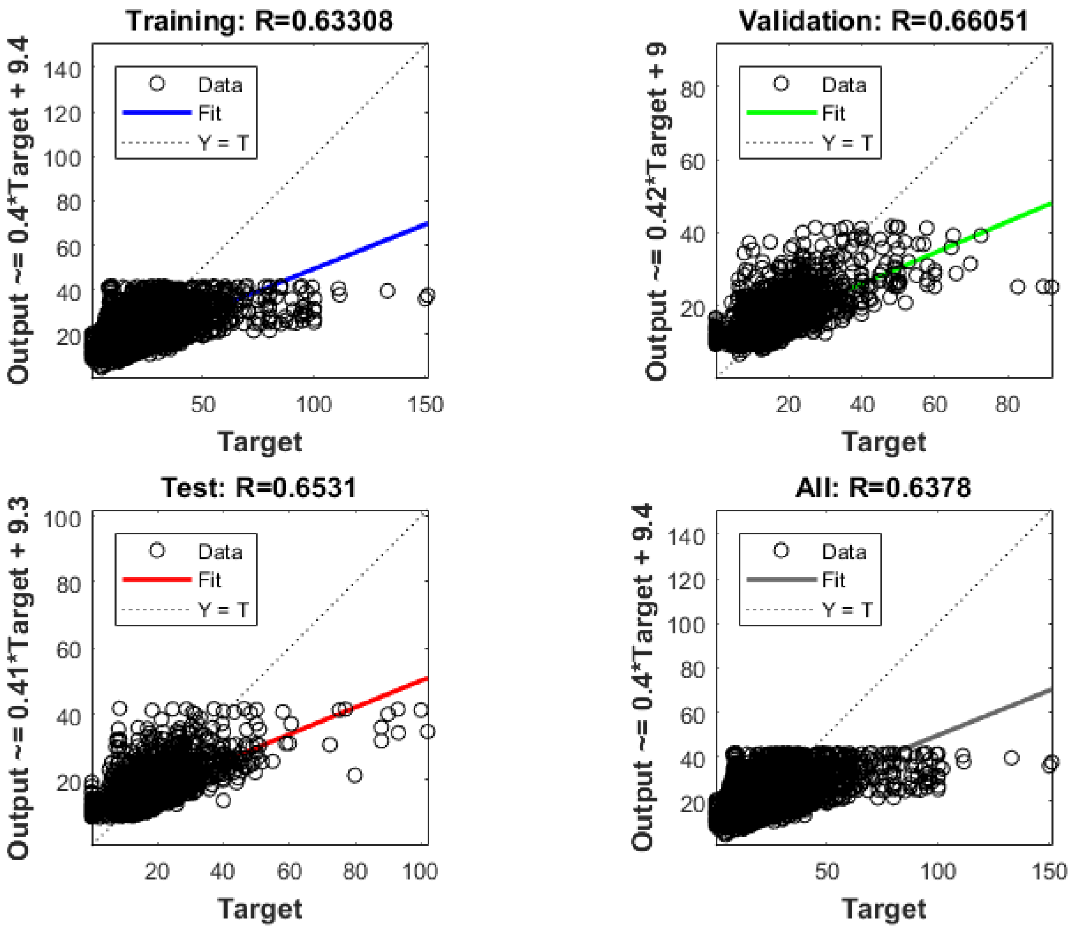


Fig 5-6 Fitting results of wholesale electricity price and demand forecasting model

In order to further study the impact of the two variables on wholesale electricity price, the objective data, supply and demand data and all data are used to forecast the wholesale electricity price. It is found that the prediction accuracy has been significantly improved with the increase of data. Relatively speaking, the forecasting accuracy of supply and demand data is higher. Of course, the import of objective data can also help improve the accuracy. The final forecasting accuracy can reach about 85%, which can meet the demand level of practical application.

Table 5-5 Forecasting results after data classification import

	Training Data	Validation data	Testing Data
Objective data	0.630	0.635	0.614
Supply and demand data	0.794	0.819	0.820
All data	0.855	0.870	0.862

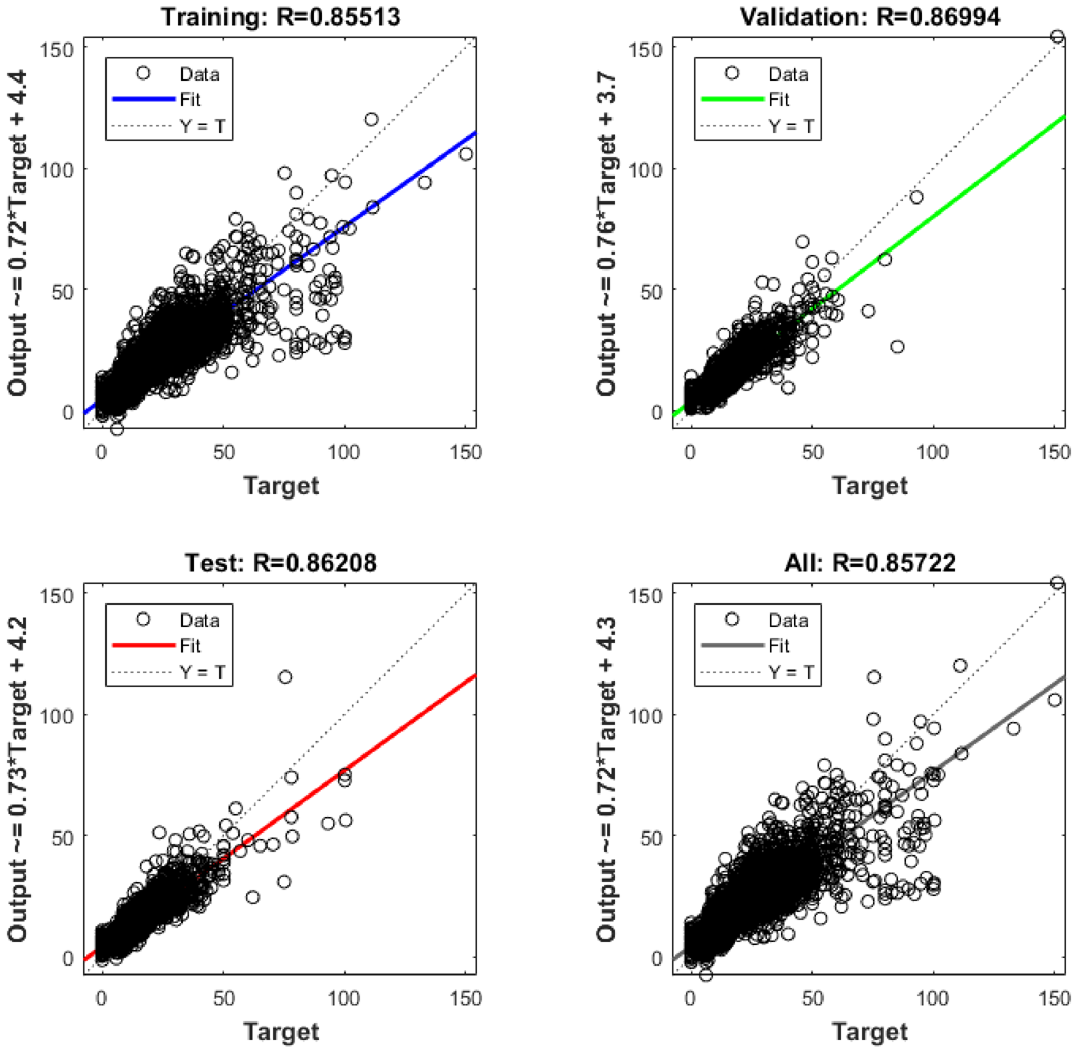


Figure 5-7 fitting results of all training data imported

5.3.3 Analysis of change regularity based on moving window

In order to better analyze the changes of wholesale market after the full opening in 2016. The data is divided by moving window. The window span is set as 1.5 years, in which one year is training and verification data, which is still divided according to the ratio of 8:2, and half a year is the test data. The window is moved at half a year interval. Figure 5-8 shows the 7 databases after partition.

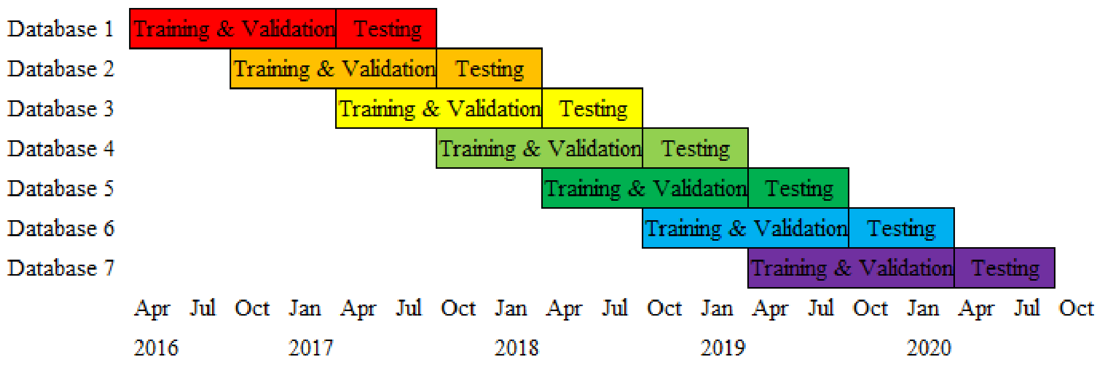


Figure 5-8 Database after moving window partition

As shown in Figure 5-9, the prediction results of seven databases are compared with the data before moving window division. It can be seen that the accuracy of training and validation data is higher than that of test data. The reason for this result is that the change regularity of the test data is different from that of the previous year, that is, the fluctuation law of wholesale electricity price is constantly changing. At the same time, the prediction accuracy dropped suddenly at 5:00 in database, which indicates that the fluctuation characteristics of electricity price have changed significantly from April to June in 2019, and this trend has eased in October, but continues to intensify in April 2020. The reason for the first obvious change is the cumulative effect of a large number of retailers entering the market. The reason for the second change was that vid-19 was related to Japan. As shown in Fig. 5-10, the forecast results of selecting 2019.4.1-2020.9.30 as the research scope, one year plus one month as the moving window range, and one month as the moving interval.

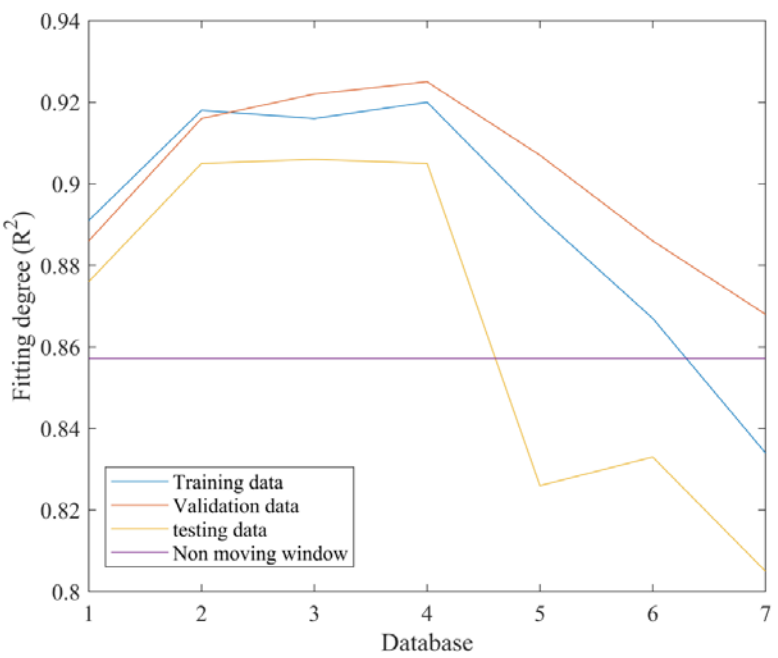


Figure 5-9 Fitting degree comparison of moving window analysis (half year)

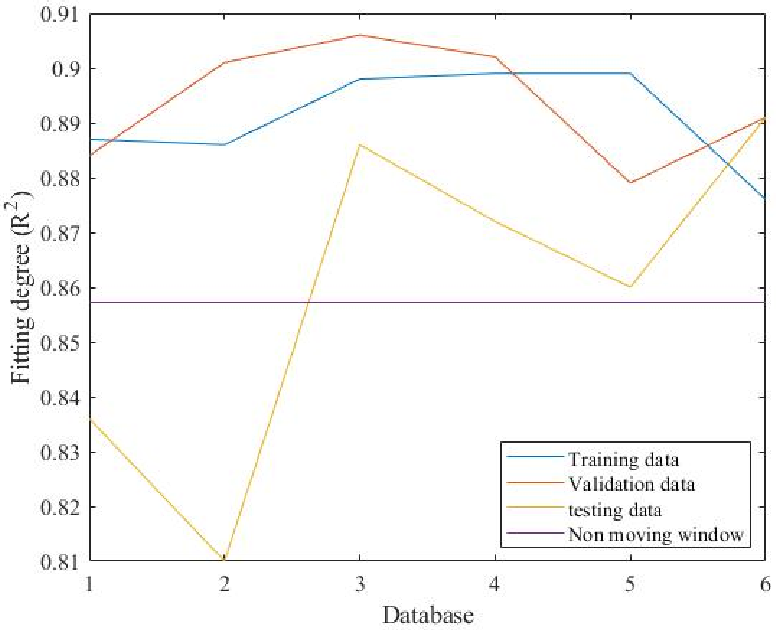


Figure 5-10 Fitting degree comparison of moving window analysis (one month)

In figure 5-10, one year's data is used as training and validation data, and one month's data is used as test data. From the results, the forecast effect in April and may of 2020 is poor, while the forecast effect in August also declines. Combined with the statistics of new cases of covid-19 in Japan in Figure 5-11, it is found that the occurrence time of the peak stage is basically the same. Therefore, it is considered that COVID-19 causes the change of power consumption characteristics on the demand side, which results in the reduction of wholesale electricity price.

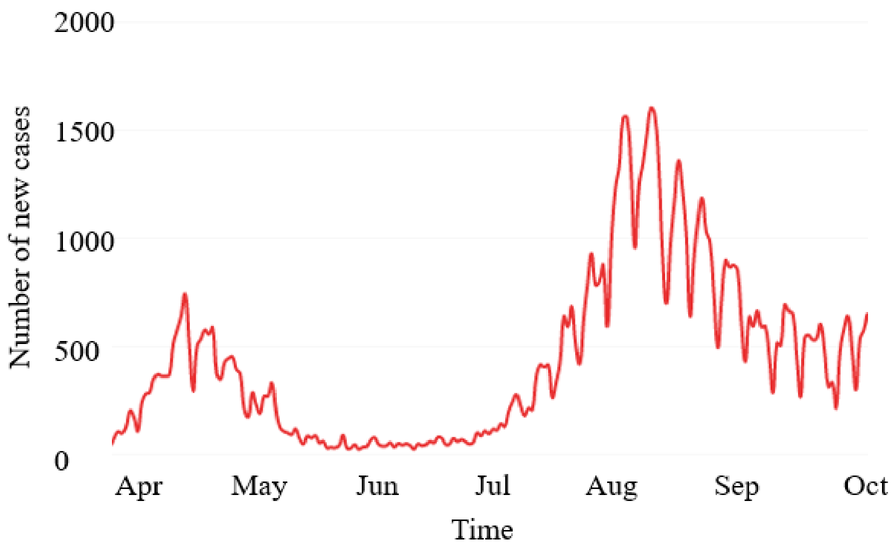


Figure 5-11 New cases statistics of COVID-19 in Japan

5.4 Energy efficiency improvement effect of demand side equipment under different electricity price modes

Although the effect of energy efficiency improvement of demand side equipment is energy saving and emission reduction, due to the different operation time, the cost savings under different electricity price modes are different. Therefore, the following will study the economic benefits of energy efficiency improvement of several common equipment under single price, step price and time of use price.

The target equipment of this study is lighting, air conditioning and hot water equipment. Through the energy efficiency improvement statistics of energy-saving equipment, the average energy efficiency improvement of equipment in five years from 2010 to 2014 is obtained, as shown in table 5-6.

Table 5-6 Average energy efficiency improvement of equipment in 2010-2014 [5]

Equipment	Promotion ratio	Equipment	Promotion ratio
Household air conditioner	1.39%	Lighting (fluorescent)	2.51%
Lighting (electric ball)	2.23%	Electric water heater	1.37%
Lighting (LED)	5.88%		

Taking the residential building as an example, due to the research on energy efficiency improvement of equipment, it is necessary to adjust the energy efficiency of the equipment. Therefore, we use designbuilder software to model, set parameters and simulate the residence. Table 5-7 shows the model and simulation parameter settings.

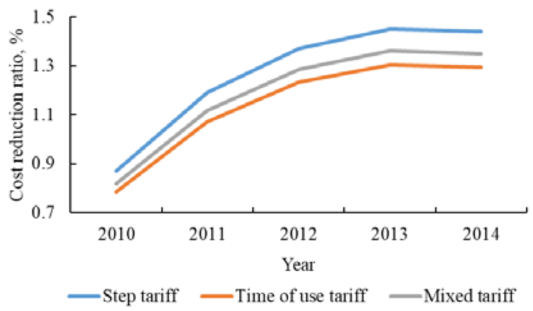
Table 5-7 Simulation parameter setting

Refrigeration start temperature, ℃	30	Heating start temperature, ℃	12
Refrigeration set temperature, ℃	26	Heating set temperature, ℃	18
Refrigeration COP	2.5	Heating COP	0.85
Domestic hot water COP	0.85	Energy use	Electricity
Personnel density, people/m2	0.025	Equipment heat dissipation, w/m2	2.16

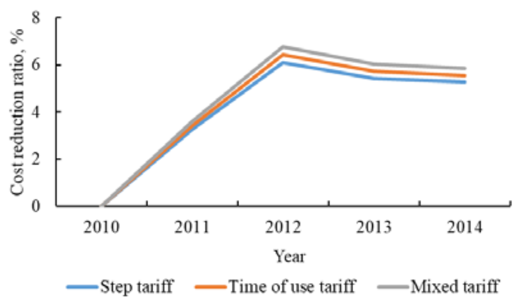
As shown in table 5-8, there are three types of tariff modes when the maximum instantaneous power demand of users is 6KVA. According to the energy efficiency improvement ratio of equipment in table 5-6, the economic benefits of energy efficiency improvement of different equipment are calculated, as shown in Figure 5-12.

Table 5-8 Electricity price model [6]

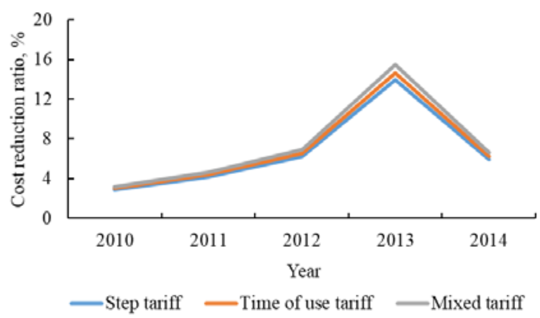
<table>
<tr><td colspan="5">Step tariff</td></tr>
<tr><td>First level</td><td>0~120kWh</td><td colspan="3">17.46Yen/kWh</td></tr>
<tr><td>Second level</td><td>121~300kWh</td><td colspan="3">23.06Yen/kWh</td></tr>
<tr><td>Third level</td><td>300 以上 kWh</td><td colspan="3">24.96Yen/kWh</td></tr>
<tr><td colspan="2">Basic capacity cost</td><td colspan="3">1782Yen</td></tr>
<tr><td colspan="5">Time of use tariff</td></tr>
<tr><td></td><td></td><td>Valley price</td><td>Daytime price</td><td>Peak price</td></tr>
<tr><td colspan="2">Other season</td><td rowspan="2">11.89Yen/kWh</td><td rowspan="2">23.24Yen/kWh</td><td>28.92Yen/kWh</td></tr>
<tr><td colspan="2">Summer</td><td>34.78Yen/kWh</td></tr>
<tr><td colspan="2">Basic capacity cost</td><td colspan="3">1650Yen</td></tr>
<tr><td colspan="5">Mixed tariff</td></tr>
<tr><td></td><td></td><td>Valley price</td><td>Daytime price</td><td>Peak price</td></tr>
<tr><td>First level</td><td>0~80kWh</td><td rowspan="3">11.89Yen/kWh</td><td colspan="2">21.52Yen/kWh</td></tr>
<tr><td>Second level</td><td>81~200kWh</td><td colspan="2">28.88Yen/kWh</td></tr>
<tr><td>Third level</td><td>201 以上 kWh</td><td colspan="2">32.82Yen/kWh</td></tr>
<tr><td colspan="2">Basic capacity cost</td><td colspan="3">1650Yen</td></tr>
<tr><td colspan="5">Valley price period: 1-8,22-24; Daytime period: 8-10,17-22; Peak price period: 10-17</td></tr>
</table>



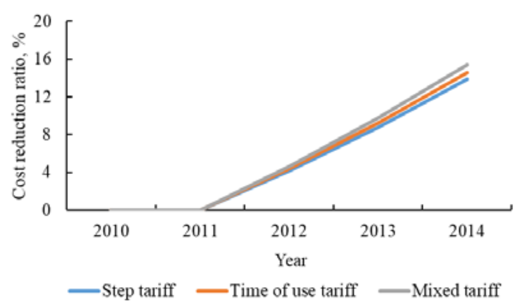
(a) Household air conditioner



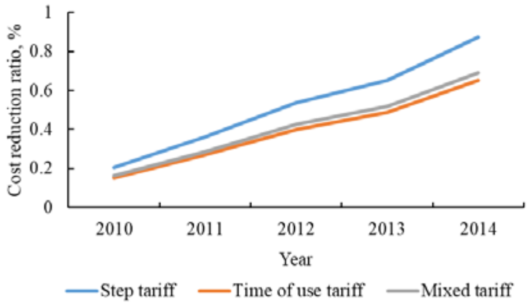
(b) Lighting (electric ball)



(c) Lighting (fluorescent)



(d) Lighting (LED)



(e) Electric water heater

Figure 5-12 Economic benefits of energy efficiency improvement of different equipment year by year

It can be seen that the most obvious cost saving effect is lighting equipment, among which LED lighting effect is the best. In terms of different electricity price models, the hybrid electricity price can provide the highest cost saving effect. For air conditioning and electric water heaters other than lighting, the stepped tariff is the most cost saving option.

Due to the different proportion of energy efficiency improvement of equipment year by year, it is impossible to make horizontal comparison. Therefore, if the energy saving effect of various equipment is set to be the same, the actual cost saving situation is shown in table 5-9.

Table 5-9 Economic benefits of different equipment under the same energy saving condition (taking 5% energy saving as an example)

		Household air conditioner	Lighting	Electric water heater
Energy consumption		2771.97	6303.82	1708.20
Target energy saving		539(5% of total building electricity consumption)		
Energy saving ratio		19.44	8.55	31.55
Annual energy efficiency improvement ratio		1.39	2.23~5.88（electric ball ~LED）	1.37
Annual energy efficiency improvement ratio (rebound effect)		1.59	0.33~0.88（electric ball ~LED）	1.56
Years to achieve energy saving		12.23	25.56~9.69（electric ball ~LED）	20.19
Cost reduction ratio	Step tariff	4.03		
	Time of use tariff	3.62	4.24	3.01
	Mixed tariff	3.78	4.48	3.19

It can be seen that due to the high proportion of annual average energy efficiency improvement of lighting, the target energy saving can be achieved in the short term. However, considering the rebound effect of energy efficiency improvement, the actual energy efficiency ratio of lighting equipment becomes the lowest. However, due to the large proportion of lighting energy consumption, the energy efficiency improvement of LED lighting is still of high value.

5.5 Effect of demand side load regulation under different electricity prices

Adding energy storage battery on demand side is one of the main means of load regulation. Take a shopping mall in Higashida area of Kitakyushu city as an example. There are only time of use price and single price in industry and Commerce in Kyushu, and there is no potential for using energy storage battery in single price. Therefore, the influence of TOU price on energy storage battery under different peak valley gap is studied. The basic calculation parameters are shown in table 5-10.

Table 5-10 Electricity price, energy storage battery price and characteristics [6,7]

<table>
<tr><th colspan="4">Electricity price</th></tr>
<tr><td></td><td>Peak time</td><td>Day time</td><td>Nighttime</td></tr>
<tr><td>Time</td><td>13~16</td><td>8~13,16~22</td><td>22~8</td></tr>
<tr><td>Summer</td><td>26.46Yen/kWh</td><td>22.36Yen/kWh</td><td rowspan="2">9.06Yen/kWh</td></tr>
<tr><td>Other seasons</td><td colspan="2">21.33Yen/kWh</td></tr>
<tr><td>Basic capacity charge</td><td colspan="2">1320Yen/kWh</td><td></td></tr>
<tr><th colspan="4">Battery</th></tr>
<tr><td>Cost</td><td>2500Yen/kWh</td><td>Discharge depth</td><td>0.8</td></tr>
<tr><td>Charge discharge efficiency</td><td>0.95</td><td>Service life cycle</td><td>10 year</td></tr>
</table>

Since only the installed capacity of the energy storage battery is an optimization goal, the golden section method is selected to optimize the single variable. Firstly, the calculation process is set as follows:

(1) Ignore the loss of power when stored in the energy storage battery.

(2) Incomplete charging and discharging is allowed in one day, but only one cycle can be completed at most.

(3) The load of the next day can be predicted accurately, so the energy storage battery can choose the load in the peak price period in summer.

The optimal battery capacity is 6336kwh, and the overall energy cost of the system is reduced by 2.1%. Furthermore, the peak valley gap of time of use price is changed to make the day price change from - 10% to 10%. In order to ensure that the initial energy cost of users remains unchanged, the night price changes accordingly. The change of electricity price is shown in table 5-11. The peak to valley ratio is shown in Figure 13-5.

Table 5-11 Variation of peak valley gap

Peak price change	Peak valley gap	Summer Peak	Summer Daytime	Daytime	Nighttime
Basic	2.92	26.46	22.36	21.33	9.06
-10%	1.68	23.81	20.12	19.20	14.14
-5%	2.17	25.14	21.24	20.26	11.61
5%	4.27	27.78	23.48	22.40	6.51
10%	7.31	29.11	24.60	23.46	3.98

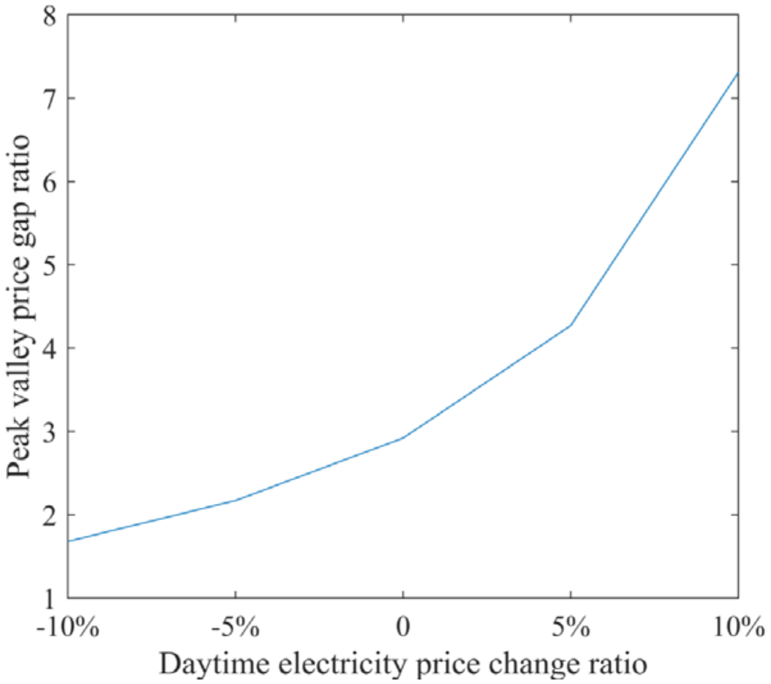


Figure 5-13 Variation of peak valley price gap ratio

It can be seen that in order to make up for the economic difference caused by the fluctuation of electricity price during the day, the price difference between peak and valley fluctuates in the range of - 42% - 150%. According to the time of use price changes in table 5-10, the battery installed capacity and energy cost reduction are obtained, as shown in figures 5-14 and 5-15. As shown in Figure 5-14, when the daytime electricity price drops by 5%, the battery can no longer generate revenue. It can be seen that the battery is extremely sensitive to the narrowing of the gap between peak and valley prices. For the increase of peak valley gap, the installed capacity presents a linear trend. This linear change can also be seen from figure 5-15. According to the trend shown in Figure 5-14, the critical point of battery revenue is that the daytime electricity price decreases by about 2.5%. According to the results of the peak valley gap change figure 5-13, it can be seen that if the peak valley gap is reduced by about 10%, the battery will not be able to generate revenue, and the impact is very obvious. Correspondingly, the gap between peak and valley increases by 150%, which can bring 4 times of economic benefits, and the promotion effect is also very obvious.

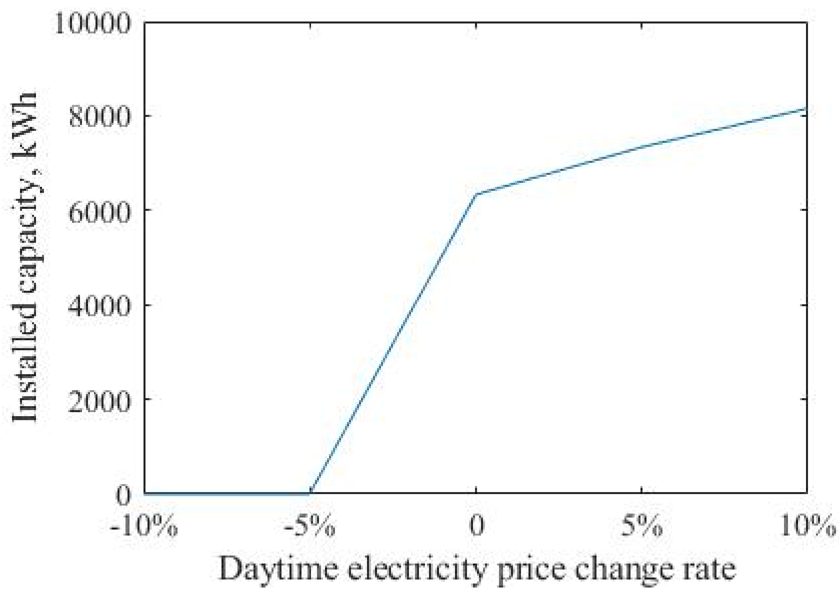


Fig 5-14 Battery installed capacity under different daytime electricity price fluctuations

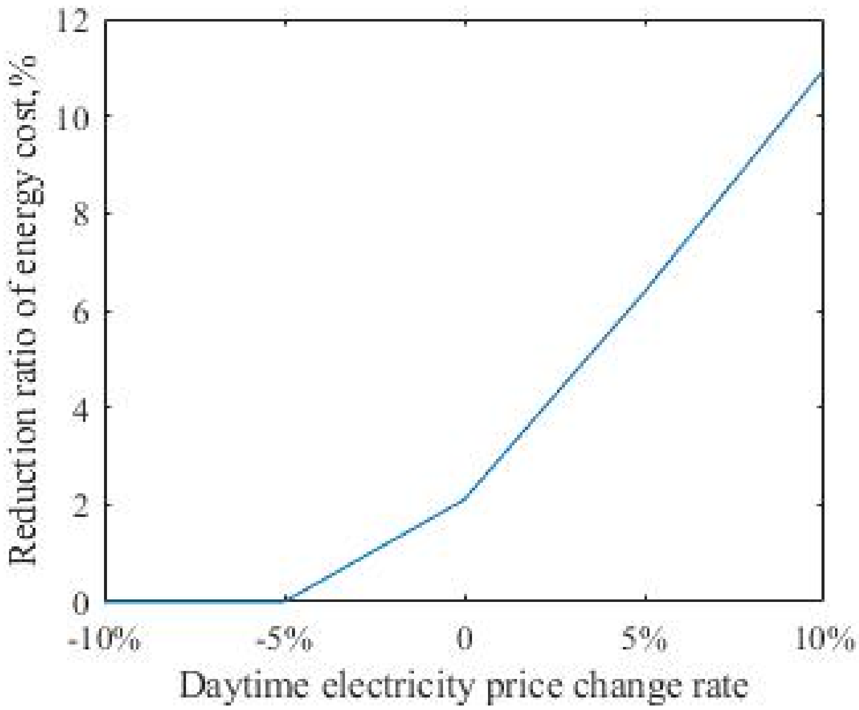


Fig 5-15 Energy cost reduction ratio under different daytime electricity price fluctuations

5.6 Summary

In order to study the specific application effect of price setting strategy in DSM. This study first analyzes the correlation between retail and wholesale average electricity prices in Japan from 2000 to 2019. The results show that the major factors affecting the price are the total demand for electricity, the proportion of wholesale electricity, the proportion of thermal power generation and the energy price of thermal power generation. It can be seen that the growth of the demand side and the promotion process of the electricity market have a positive significance for the decline of electricity price. After that, the hourly wholesale electricity price analysis from 2016 to 2020 is carried out. Through the mobile window + LMBP method, the analysis shows that after the full opening of the power market in 2016, the volatility of wholesale electricity price begins to fluctuate obviously in 2018 after two years of gentle development. At the same time, combined with the relevant data of covid-19 in 2020, it is found that the sharp fluctuation of wholesale electricity price in 2020 mainly comes from the power demand change brought by the epidemic situation. The importance of demand side is further emphasized.

Next, taking the residential building as an example, the power consumption of the demand side is obtained through the simulation of designbuilder software. By modifying the equipment efficiency of lighting, air conditioning and electric water heater, this paper studies the efficiency improvement effect of the equipment under the step price, time of use price and hybrid price. The results show that the hybrid electricity price can bring maximum benefits to the energy efficiency improvement of lighting equipment. Step tariff can bring the highest benefit to air conditioner and electric water heater. At the same time, the improvement of lighting energy efficiency has the most obvious effect, but considering the rebound effect of users, only LED has practical significance.

Finally, taking a shopping mall in Higashida area of Kitakyushu city as an example, the influence of different peak valley gap of TOU price on battery energy storage is studied. The results show that if the initial energy cost remains unchanged, the battery will lose its economic benefits if the peak price only drops by 2.5%. However, if the peak price is increased by 10%, the gap between peak and valley will be increased by 150%, and the economic benefits will be increased by 4 times, which will have a significant impact.

Through the analysis of the influence factors of electricity price and the technical side means, this paper studies the limitation and effect of economic side means of demand side management. The conclusion has a good practical reference value.

Appendix

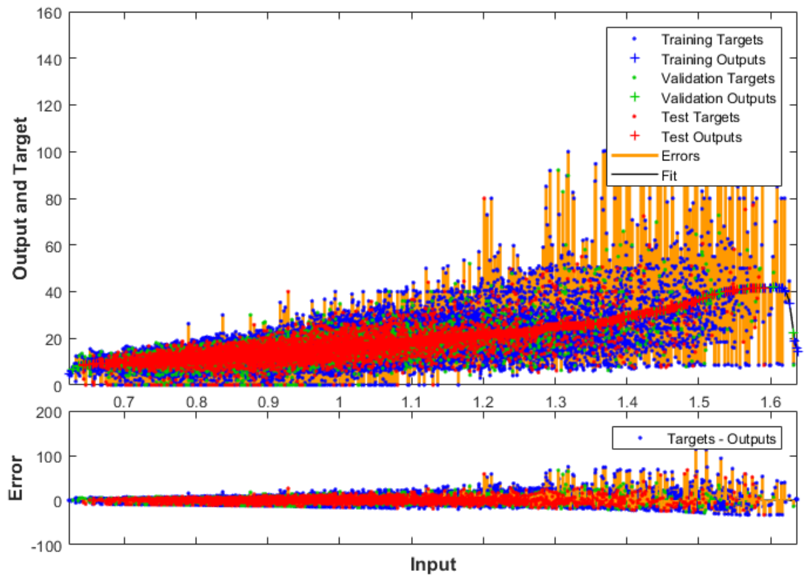


Figure A-1 Data distribution and error

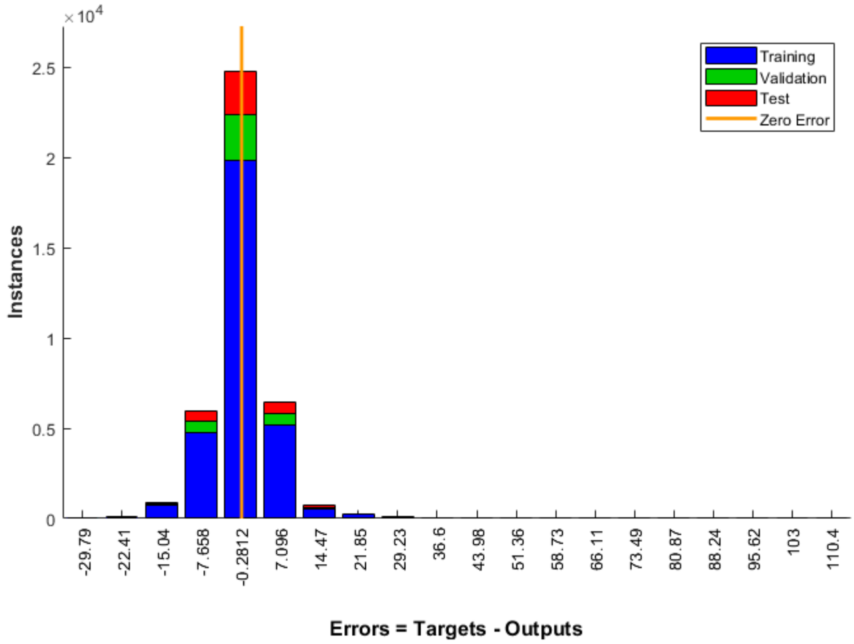


Figure A-2 Error statistics

Reference

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Chapter 6

ANALYSIS OF DEMAND SIDE ADAPTABILITY UNDER THE JOINT ACTION OF TECHNOLOGY AND ECONOMIC MEANS

CHAPTER SIX: ANALYSIS OF DEMAND SIDE ADAPTABILITY UNDER THE JOINT ACTION OF TECHNOLOGY AND ECONOMIC MEANS

6.1 Content

In order to adapt to the development of new technologies on the demand side and the continuous advancement of the process of electricity market liberalization, In this research, the optimal configuration and load adaptability of microgrid system based on the introduction of V2G mode of electric vehicle and different demand side liberalization scenarios are proposed. The electricity demand data of 49 buildings in the target area are reduced. The data are divided into six clusters by factor analysis and cluster analysis, and six typical electric load centers are obtained. Then, three different demand side liberalization scenarios are set up: (1) self use; (2) photovoltaic(PV) on grid pricing policy; (3) electricity free trade. Through Monte Carlo simulation, the state and residence time of electric vehicles are obtained, and the micro grid configuration is optimized by genetic algorithm. Through the analysis of the optimization results and the comparison of load characteristics of different clusters, the adaptability of different types of loads participating in the demand side microgrid construction is studied.

6.2. Methodology

The research method of this study is shown in Figure 6-1. Firstly, the typical demand side user load is obtained by factor analysis and cluster analysis. Then, the permissible discharge capacity of V2G service is simulated by Monte Carlo method. Then, the genetic algorithm is used to optimize the configuration of microgrid system, and the comparison of the degree of liberalization of different users' energy systems is obtained.

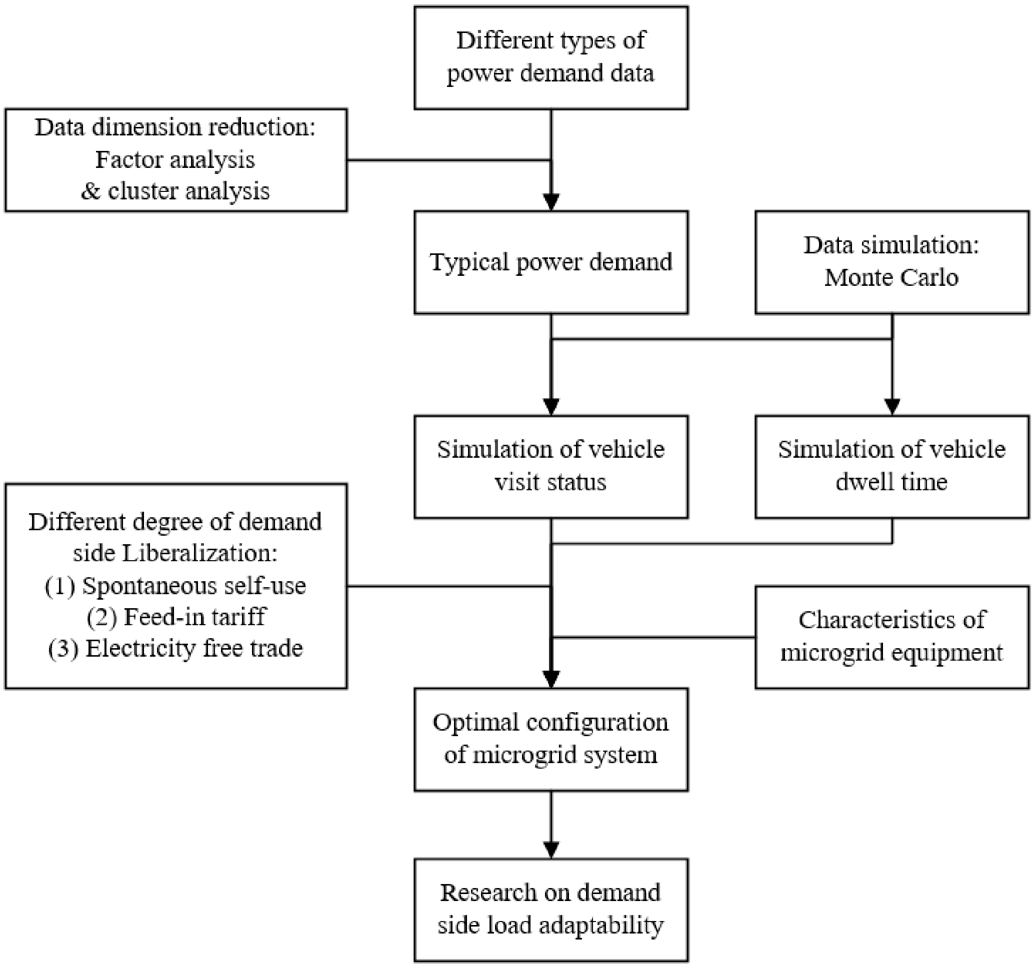

Figure 6-1 Research Method and Process

6.2.1 Electricity balance of microgrid system

The aim of this paper is the demand side microgrid system. The conventional microgrid system is a hybrid system of renewable energy, gas-fired generation and battery. Due to the high price of natural gas in Japan, gas-fired generation is more used in cogeneration system. Therefore, only the combination of PV and battery is considered in this paper, and the V2G system of electric vehicle is added to form a new microgrid system, as shown in Figure 6-2.

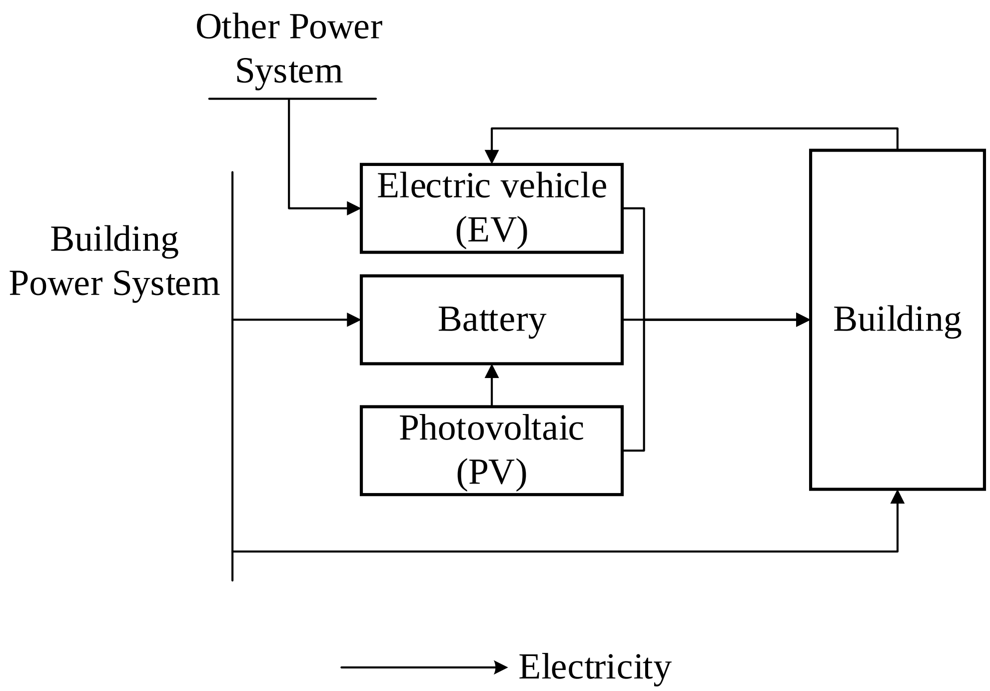

Figure.6-2 Schematic diagram of demand side microgrid system

PV stores excess electricity into batteries while generating electricity to the building. Furthermore, the battery also stores electricity from the building electricity system at low electricity prices and releases this electricity at high electricity prices. On the one hand, electric vehicles may be recharged from other electricity systems before arriving at the building parking lot. On the other hand, they can also be recharged from the electricity system of the target building after reaching. When there is a large amount of electricity, it will participate in V2G service and reverse discharge to the building. The balance formula of electricity supply and demand of the system is:

$$E_{load}^{t} = E_{PV}^{t} + E_{Battery}^{t} + E_{EV}^{t} + E_{Grid}^{t} \quad (6\text{-}1)$$

E_{PV}^{t}, $E_{Battery}^{t}$, E_{EV}^{t} and E_{Grid}^{t} are the power generation of PV, battery, EV and power from grid.

6.2.2 Monte Carlo simulation and visiting vehicle model

Monte Carlo, also known as statistical simulation method, is a numerical statistical method that takes probability events as simulation objects. It is suitable for the simulation of random events with certain regularity. It is often used to study the reliability of equipment and system in the field of energy. At the same time, it is also used in the research of some V2G. In this paper, since it is necessary to determine the state and residence time of different electric vehicles visiting buildings. Hence Monte Carlo simulation is used to simulate the maximum permissible discharge capacity of electric vehicles when participating in V2G services[1].

（1）Visit status

t is considered that the electric vehicle is fully charged when it starts from the residence every day. According to the National Household Travel Survey (NHTS) conducted by the U.S. Department of Transportation in 50 states. The logarithmic variation of daily mileage of electric vehicles is a normal function[2]:

$$f_d = \frac{1}{x \times \sigma_d \times \sqrt{2\pi}} e^{-\frac{(Ind-\mu_d)^2}{2\times\sigma_d}} \quad (6\text{-}2)$$

Among them, Ind represents the logarithm of mileage, μ_d is the expected number of kilometers, σ_d is the standard deviation. The two are 3.2 and 0.88 respectively.

According to the calculation of the mileage of the visited vehicle, the residual electricity of the electric vehicle can be obtained, formula 6-3. If the remaining electricity exceeds 50%, it can participate in V2G service for reverse discharge.

$$EV_{residue}^{i} = (1 - P_{use}^{i} \times d_t^i) \quad (6\text{-}3)$$

Among them, i is the ith electric vehicle and t is the visiting time. $P_{use}^{i}$is the power consumption per mileage, kWh。$d_t^i$is the mileage traveled, km。

(2) Charge discharge model

The charge discharge model of electric vehicle is the same as that of battery. It can be expressed as the state model of battery:

$$SOC_{t+1}^{i} = SOC_t^i + \left(P_{in}^i \times in_t^i \times \varepsilon_{battery} - P_{out}^i \times out_t^i \times \varepsilon_{battery}\right)\Delta t \quad (6\text{-}4)$$

Among them, P_{in}^i和P_{out}^i is the charge discharge electricity, kWh/h; in_t^i和$out_t^i$is the control signal of charge and discharge; $\varepsilon_{battery}$is the charge discharge efficiency, %。

6.2.3 Economic Model

（1）Discharge loss and elastic coefficient of V2G

The discharge behavior of electric vehicle is a kind of loss of its own battery, so this part of loss should be considered in the discharge price:

$$C_{out}^{EV} = C_{house}^{EV} + \frac{C_b}{k \times Number \times SOC_{max}^{i} \times \mathrm{DoD}} \quad (6\text{-}5)$$

Among them, $Price_{house}^{EV}$ is the charging price of electric vehicles in their residence. $C_b$is the investment price of electric vehicle battery, Yen/kWh。k is the cycle multiple 3, $Number$is the number of cycles of the battery, 2000 times, $SOC^{i}_{max}$is the maximum capacity of the battery, DoDis the discharge depth, 80%。

Because not all electric vehicles with more than 50% residual capacity are willing to discharge in the direction, the elastic coefficient based on user behavior is introduced. It is considered that the proportion of electric vehicles willing to discharge is related to the discharge price:

$$\Delta EV^{i}_{residue} = EV^{i}_{residue} - \varepsilon \frac{C^{EV}_{house} \times EV^{i}_{residue}}{(C^{EV}_{house} - C^{EV}_{out})} \quad (6\text{-}6)$$

Among them, $\Delta Eout_t$is the maximum discharge that is willing, kWh。$\varepsilon$is the elastic coefficient, -1.55[3]。

（2）Energy Cost Model

The energy cost of demand side microgrid system is shown in formula 6-7:

$$cost = cost_{system} + cost_{maintain} + cost_{energy} \quad (6\text{-}7)$$

Among them, $cost_{system}$is the equipment investment of demand side microgrid system, The formula is as follows:

$$cost_{system} = \sum cost_j (6\text{-}8)$$

j refers to different energy equipment, including PV, battery and V2G equipment.

$cost_{system}$ is the maintenance cost of the system. The maintenance cost is considered to be 2% of the system investment:

$$cost_{maintain}=2\%cost_{system}(6\text{-}9)$$

$cost_{energy}$is the user's electricity fees:

$$cost_{energy} = \sum E^{t}_{Grid} \times E_{price}(6\text{-}10)$$

Among them, E_{price} is the price of electricity used by consumers.

6.2.4 Objective Function and Boundary Conditions

The objective of this paper is to minimize the total energy cost (formula 6-11). The limiting conditions of the objective function are shown in formulas 6-12, 6-13 and 6-14, that is, batteries or electric vehicles cannot be charged and discharged at the same time.

$$\min\,(cost) = \min\,(cost_{system} + cost_{maintain} + cost_{energy}) \quad (6\text{-}11)$$

$$in_t^i = \begin{cases} 1 & Charge \\ 0 & Non\,Charge \end{cases} \quad (6\text{-}12)$$

$$out_t^i = \begin{cases} 1 & Discharge \\ 0 & Non\,Discharge \end{cases} \quad (6\text{-}13)$$

$$in_t^i + out_t^i \le 1 \quad (6\text{-}14)$$

6.3. Case Study

6.3.1 Case introduction

The target area of this paper is Higashida area (Figure 6-3) in kitakushu Japan. As the core of the development of environment-friendly city, the area has been taking "smart community" as the goal since its establishment, and has carried out a number of green energy and smart energy demonstration projects such as distributed roof PV, hydrogen energy, energy-saving housing and other green energy and smart energy demonstration projects. At the same time, most of the buildings in the area also maintain the habit of efficient electricity use. Therefore, the electricity load data collected in this paper can also represent the situation of different types of buildings with high energy utilization level, and have high practical application value.

Figure 6-3 schematic diagram of Higashida area [4]

The object of this paper is 49 buildings in Higashida area. As shown in Figure.6-4, the hourly electricity load of all buildings is sorted from large to small. In order to facilitate comparison, 0-1 standardization method is adopted.

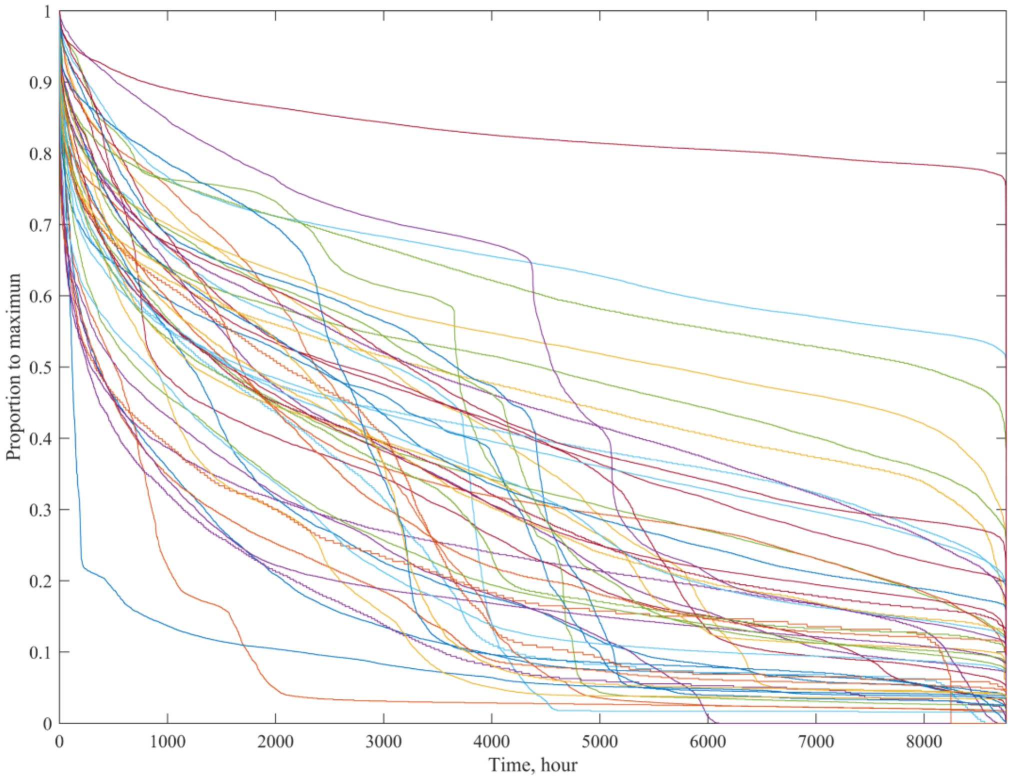

Figure 6-4 0-1 hourly electricity load ranking from large to small after standardization (49 buildings)

It showned that the load variation characteristics of these buildings are quite different. Therefore, the building types and load characteristics of all buildings are counted, as shown in table A-1 in the appendix. The load characteristics include total electricity load (TEL), average load (AL), load standard deviation (LSD) and coefficient of variation (CV). TEL and AL are used to reflect the volume of electricity demand, and LSD and CV are used to reflect the fluctuation of load. It can be concluded that among the 49 buildings, commercial and office buildings account for the largest proportion, but even in the same type, there are buildings with different load characteristics. Therefore, through factor analysis and cluster analysis to reduce the dimension, select the most suitable representative of the typical load of these buildings for the next step of optimization calculation.

6.3.2 Load Analysis and Dimension Reduction

（1）Factor Analysis

All building loads are standardized from 0 to 100 in order to better reflect the impact of load characteristics. Then, through factor analysis, the characteristic values of different building loads are obtained (Figure. 6-5).

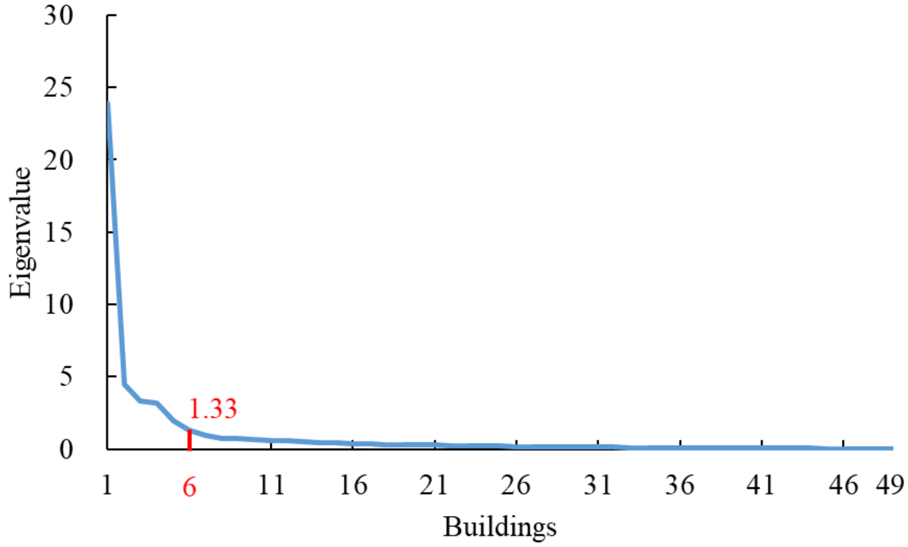

Figure. 6-5 Steep slope map of eigenvalue

It can be seen that when the number of buildings is 6, the contribution to the eigenvalue decreases to 1.33, and the contribution from the seventh building is less than 1. Therefore, it is considered that six typical buildings can represent all 49 buildings, that is, the optimal number of cluster centers in the subsequent cluster analysis is 6.

(2) Cluster Analysis

Through K-means clustering analysis, the clustering results based on six clustering centers are obtained, as shown in Table 6-1. As shown in Figure 6-6, the hourly electricity 0-1 of different cluster centers is sorted from large to small after standardization, and the typical weekly daily load change of cluster center point 1 is shown in Figure 6-7 (other clusters are shown in Appendix B-1, B-2, B-3, B-4, B-5). Combined with the load volatility in table A-1, the cluster centers are analyzed. It can be seen that cluster 1 mainly represents residential buildings, hotels, hotels and other buildings with low load volatility and electricity demand in the daytime and at night. Cluster 2,5,6 are mainly office and factory buildings. The load fluctuation of cluster 5 is the most gentle. Cluster 2 is more inclined to buildings with shorter working hours. The working time of cluster 6 is longer. Cluster 3 and Cluster 4 represent commercial buildings, of which cluster 3 is more inclined to shopping malls and the load change is relatively gentle during business hours, while Cluster 4 has relatively high load demand in the morning.

Table 6-1 cluster analysis results

Cluster center		1	2	3	4	5	6
Building type	Convenience Store	2				1	
	Experimental building		3				
	Factory		1				5
	Gas station	1					
	Hospital	2					
	Hotel	1					
	Museum		2				
	Office	1	5			2	9
	Railway platform	1					1
	Residential	2					
	Shopping			8	2		

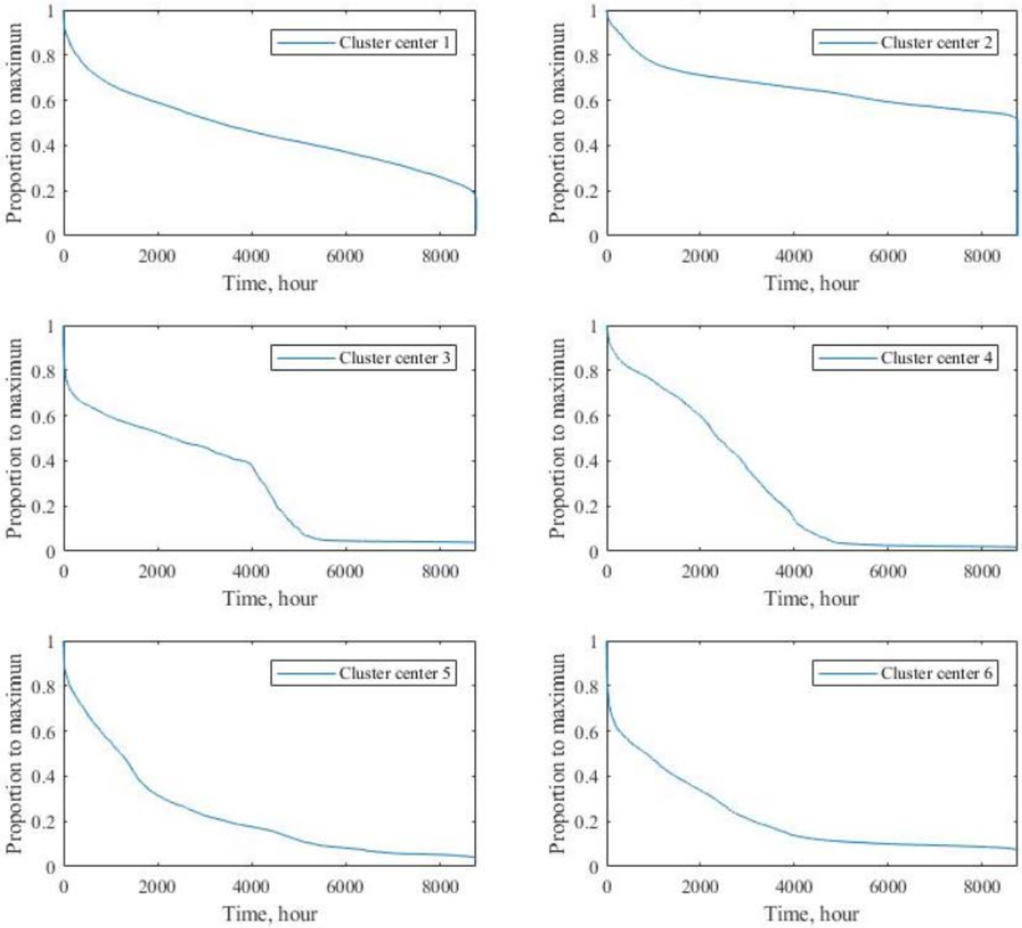

Figure.6-6 0-1 Ranking of hourly electricity load after standardization from large to small (cluster center)

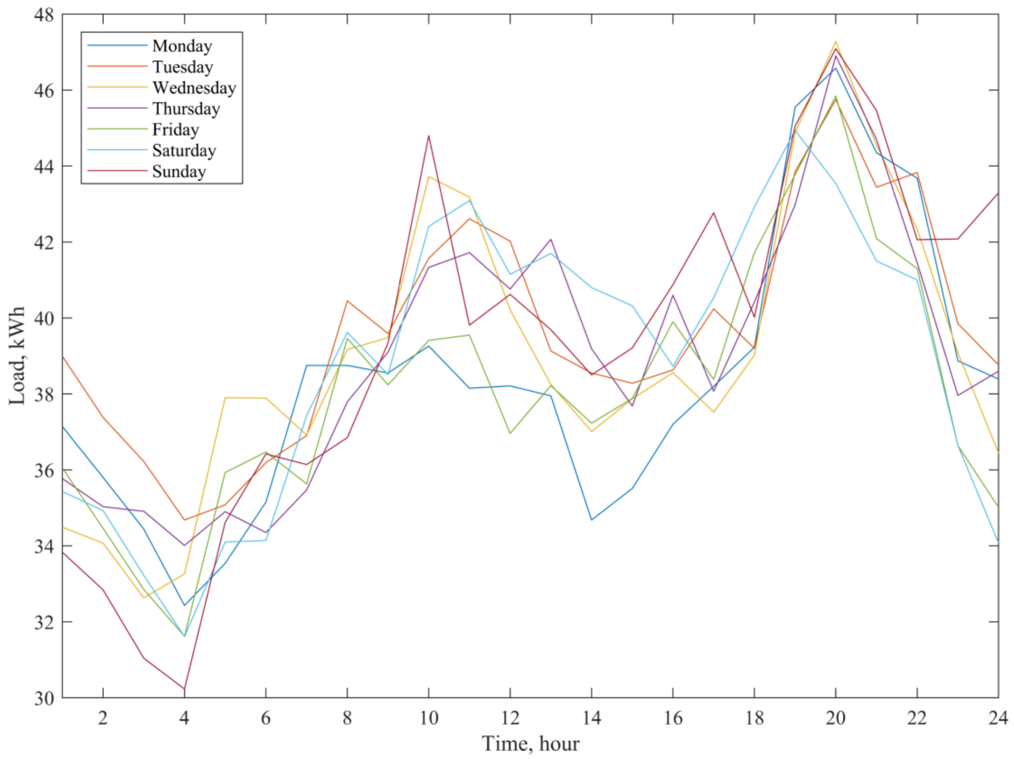

Figure 6-7 Typical weekly daily load change of cluster center 1

6.3.3 Monte Carlo simulation of discharge capacity of electric vehicle

After getting the six clustering centers which need to be optimized, the visiting state and residence time of electric vehicles in different buildings need to be simulated by Monte Carlo simulation. The main process of simulation is as follows:

(1) The business hours of the target building are set, the parking lot is closed outside the business hours, and there are no visiting vehicles. During business hours, due to the electricity load demand of the building, in addition to the commonly used equipment, it is mainly related to the personnel density in the building. Therefore, it is considered that there is a positive correlation between electric load and visiting vehicles. Further more, it is considered that the target building will reach the maximum number of vehicles visited each month, and the rest of the time is converted according to the ratio of the hourly electricity load to the monthly maximum electricity load.

(2) According to the expected value and standard deviation of the mileage that the vehicle has driven in different time periods, the state of the visited vehicles per hour is simulated. The expected value is 3.2 and the standard deviation is 0.88.

(3) According to the expected value and standard deviation of vehicle dwell time, the vehicle dwell time is simulated. The expected value is 1.5 and the standard deviation is 1.

4) It is considered that the unit hourly discharge capacity of electric vehicle is the same as the charging electricity of EV, which is 6kW. The EV discharge capacity of different timelines is superimposed and divided by the set number of charging piles (100 per building) to obtain the hourly capacity of each V2G service charging and discharging device (Take April 1 of cluster center 3 as an example) as shown in Figure 6-8. It can be seen that although the visiting time of vehicles is related to the electricity load, due to the different stay time, the maximum discharge capacity appears one hour before the end of business. This has a certain dislocation with the load demand, but it is more consistent with the actual situation.

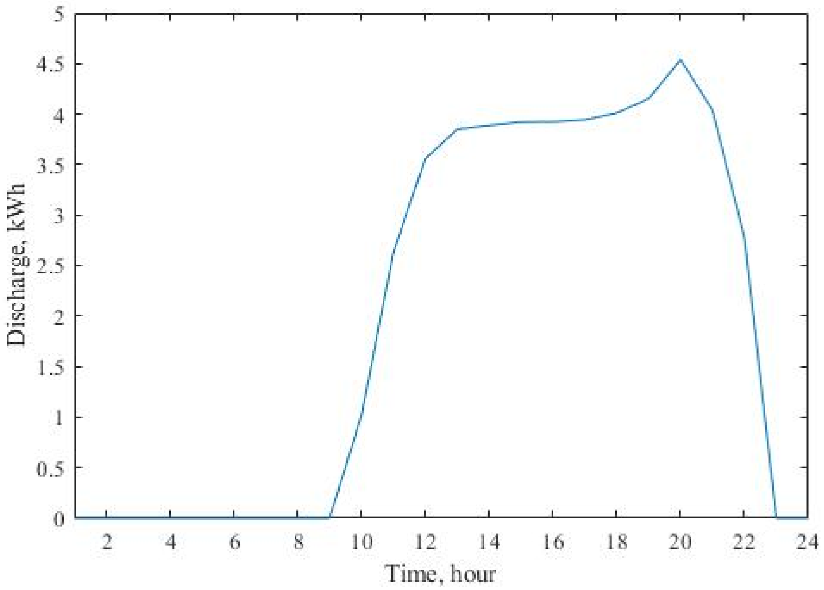

Figure 6-8 Typical daily discharge capacity of each V2G service unit

6.3.4 Assumptions and basic parameters

After completing the simulation of EV, considering that the system may be limited by objective conditions and the actual operation process is more complex. The following assumptions are made:

(1) When EV participates in V2G service, the maximum instantaneous load of reverse discharge to the target building does not exceed the electricity load demand of the target building, and there is no case that the excess discharge is stored by the energy storage battery.

(2) When PV produces light discarding, it is stored by energy storage battery. Ignoring the situation that the energy storage battery has no space left, it is considered that the energy storage battery has reserved enough capacity based on the previous day's power generation of PV forecast. And the energy storage battery can only be charged and discharged once a day.

(3) The limitation of roof area, the permeability of PV is limited to some extent. Therefore, the

maximum PV penetration rate is set as 20%. In the optimization, the optimal energy storage and V2G configuration under different PV permeability will be calculated from 0-20% with an interval of 2%.

(4) According to the operation of a distributed roof PV system near the study area, the annual effective utilization hours are 940 hours.

In the process of optimization, it is necessary to set the energy price and equipment cost, as shown in table 6-2 and table 6-3.

Table 6-2 Energy price setting [5]

Time			Prices
Summer	Peak time	13:00-16:00	26.46 (yen/kWh)
	Daytime	8:00-13:00,16:00-22:00	22.36 (yen/kWh)
Other seasons	Daytime	8:00-22:00	21.33 (yen/kWh)
Night		22:00-8:00	9.06 (yen/kWh)
Peak load price		Monthly	1320 (yen/kW)

Table 6-3 equipment performance parameters and prices [6,7]

System	Capital cost	Lifetime	Other characteristics
PV	200000 (yen/kW)	30	
Battery	150000(yen/kW)	10	Charge discharge depth: 15%-95% Charge discharge efficiency: 95%%
V2G device	460000	20	Charge discharge power: 6kW

6.4. Result analysis

By modeling and optimizing the demand side microgrid system combining PV, battery and V2G services, the system optimization under three different conditions is considered according to the degree of liberalization of the demand side:

(1) Case 1, Spontaneous self use: All the electricity produced by users must be consumed by themselves.

(2) Case 2, PV Feed-in tariff: Users are allowed to sell PV power generation to the grid, and users can choose to use or sell PV electricity to the grid.

(3) Case 3, Electricity free trade: One or more buildings with high adaptability of microgrid system are responsible for the construction of microgrid, and the surplus electricity is traded to other buildings.

6.4.1 Spontaneous self-use

It is impossible to sell the surplus electricity to the electricity grid. Therefore, in the operation strategy of case 1, the energy storage needs to give priority to the storage of surplus PV, and the PV power generation that cannot be stored is treated as light abandonment. As shown in Figure 6-9 below, the energy cost reduction of six cluster centers is shown for each 2% increase of PV penetration under different PV penetration rates. It can be seen that the basic energy cost reduction is between 1% and 1.5%, and the highest energy cost reduction of the six cluster centers is about 13% - 14% when the PV penetration rate is increased to 20%.

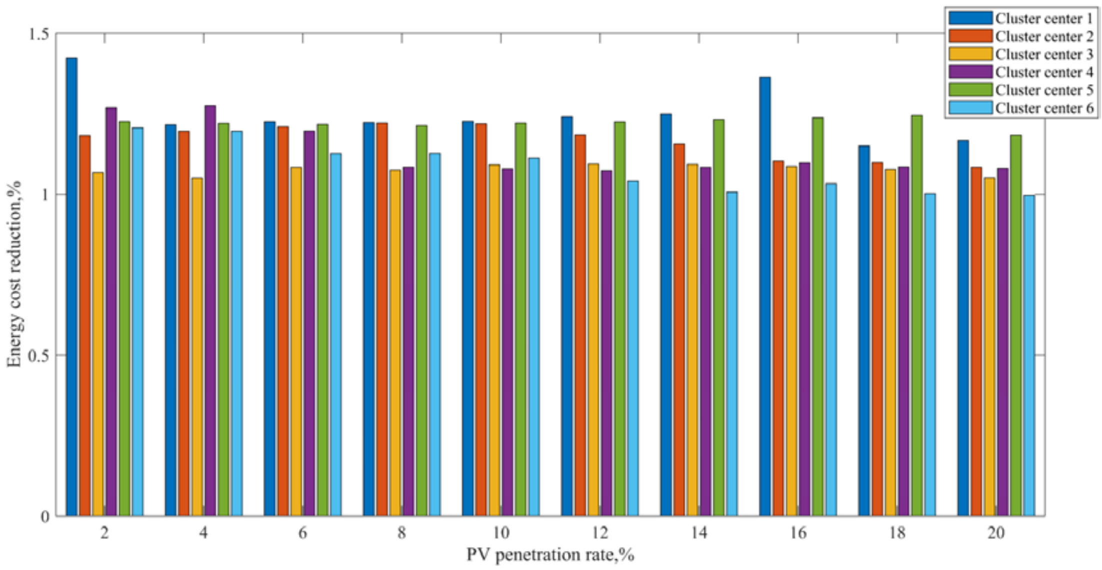

Figure 6-9 Energy cost reduction under different PV penetration rates

It can be seen that the construction of demand side microgrid system in the six cluster centers has high economic benefits, but the optimization results show that the optimal equipment configuration of different cluster centers is quite different. Figure 6-10 shows the number of V2G devices at different PV penetration rates. It shows that PV has a great impact on the economic benefits of V2G equipment. With the continuous improvement of PV penetration rate, on the one hand, the PV power generation revenue has been improved, on the other hand, due to meeting more user loads, the unit revenue of V2G services has decreased, resulting in the reduction of V2G equipment. Therefore, the reduction of energy cost fluctuates in a fixed range. This indicates that cluster center 1, 3 and 5 all have a high number of V2G devices at the beginning. Meanwhile with the increase of PV penetration rate, the decline rate of cluster center 5 is the fastest and that of cluster center 3 is the slowest. However, the V2G services of cluster centers 2, 4 and 6 could not produce enough economic benefits at the beginning, so it was maintained in a low range. In the six cluster centers, there are surplus PV power generation, accounting for about 2% - 3% of the PV power generation proportion. Among them, only 1 and 5 have the situation that the surplus PV power generation cannot be stored, resulting in light abandonment, as shown in Figure 6-11. The number of cluster center 1 is less, and it begins to appear when the PV penetration rate reaches 6%. Cluster center 5 has a large amount of light discarding, which begins to appear when the permeability reaches 4%.

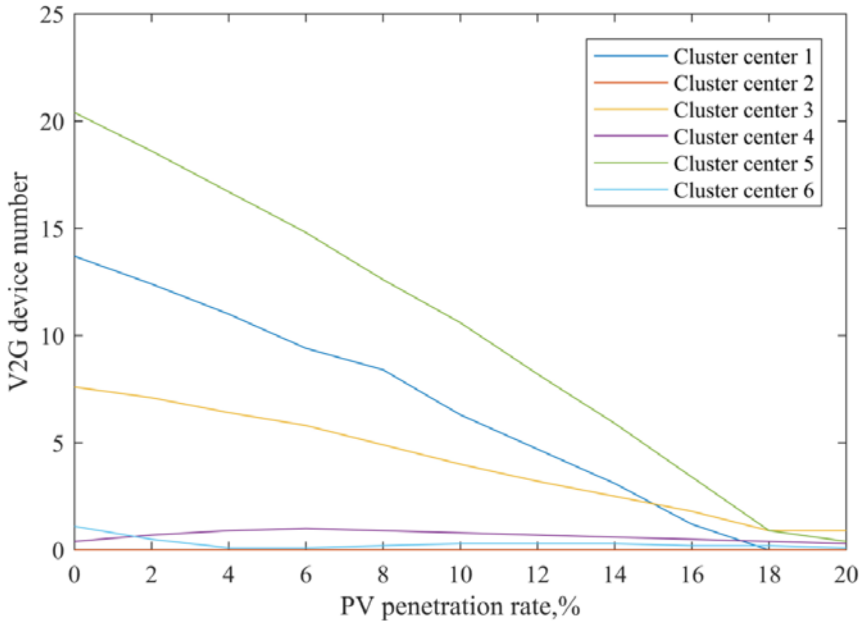

Figure 6-10 The number of V2G devices varies with PV permeability

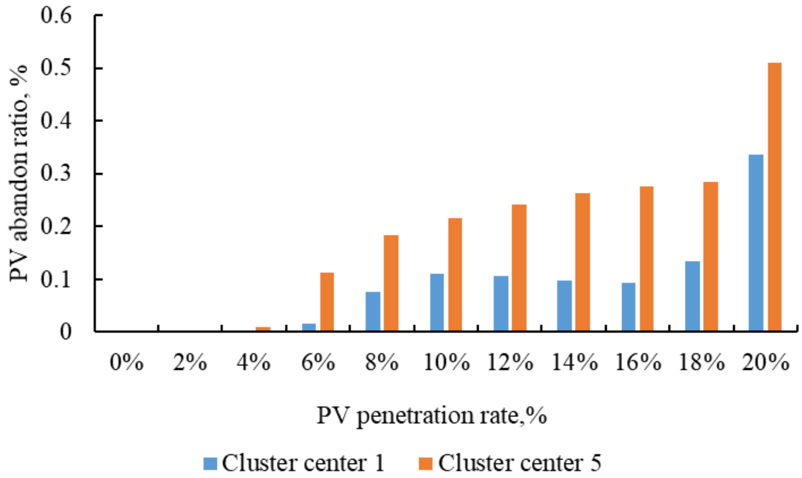

Figure 6-11 Relationship between the amount of PV light discarded and the PV light discarded by the battery (cluster center 1)

The relationship between the energy supply structure of cluster center 1 and PV permeability is shown in Figure 6-12. The results of other cluster centers are shown in B-6, B-7, B-8, B-9 and B-10 in Appendix. Similar to the results in Figure 6-9, the electricity supply of V2G decreases with the increase of PV penetration. However, it can be seen from Figure 6-10 that the supply ratio of V2G in cluster center 1 can reach about 37% without PV. Therefore, cluster centers 1 and 5 (residential, hospital and office) are more suitable for the system composed of V2G and battery from the perspective of demand side self-sufficiency rate and light rejection rate. Cluster centers 2, 4 and 6 (office, commercial and factory) are more suitable for battery and PV systems. Cluster center 3 (commercial) can maintain the self-sufficiency rate in the range of 23% - 24%, which is suitable for the energy system composed of V2G, battery and PV equipment.

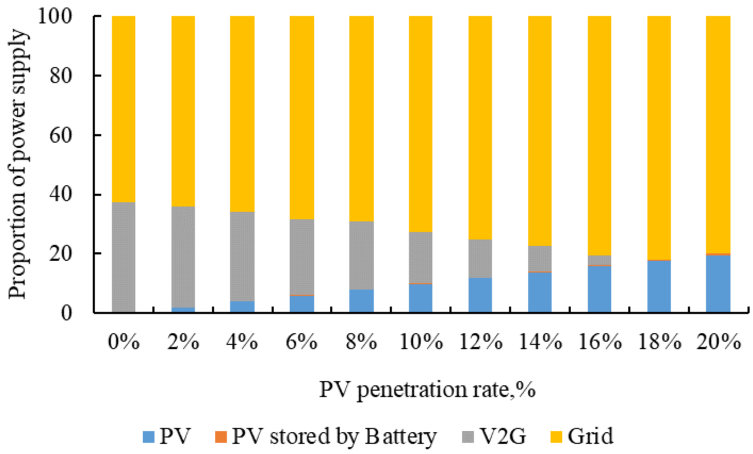

Figure 6-12 Energy supply structure changes with PV penetration (cluster center 1, residential, hotel and hospital buildings)

6.4.2 Feed-in Tariffs

The surplus electricity of demand side microgrid system can not be used, which is the main reason to limit the economic benefits of microgrid system. Then consider increasing the degree of liberalization on the demand side to allow electricity to be sold to the grid. At present, only distributed PV and wind power generation have relevant policies in Japan, so this paper only considers the situation of PV power generation on grid, that is, Japan's feed-in-tariffs (FIT) policy.

When PV power generation can be sold to the grid, users can get the most economic use of PV power generation through the comprehensive optimization of their own electricity price and grid price. According to Japan's FIT policy, in the initial distributed PV system, the feed-in tariffs can reach 31 yen, and the feed-in tariffs continues to decline with the development of time. This paper studies the fluctuation of the feed-in tariffs in the range of 31-10 yen, and obtains the relationship between the energy cost reduction and the PV feed-in tariffs as shown in Figure 6-13. Taking cluster center 1 as an example, with the decrease of feed-in tariffs, the economic benefits of microgrid gradually decrease and eventually tend to fixed value. Comparing the degrees of freedom of the two demand side microgrid systems in Figure 6-14, when the PV penetration rate is 20%, the final economic benefits of the microgrid will tend to be consistent when the feed-in tariffs is reduced to 12 yen, that is, the policy of PV feed-in tariffs can no longer generate revenue.

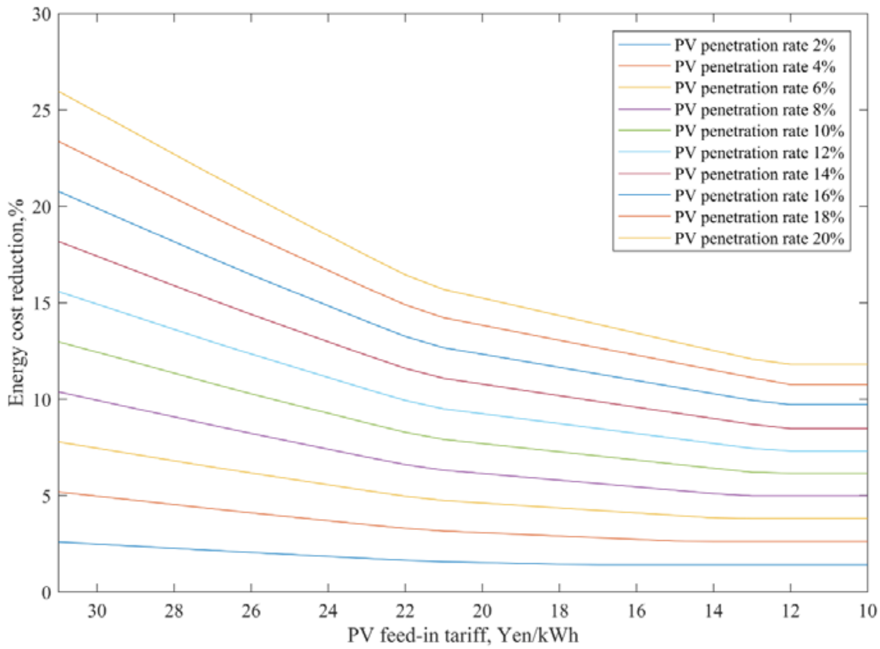

Figure 6-13 Relationship between energy cost reduction and PV grid price (cluster center 1)

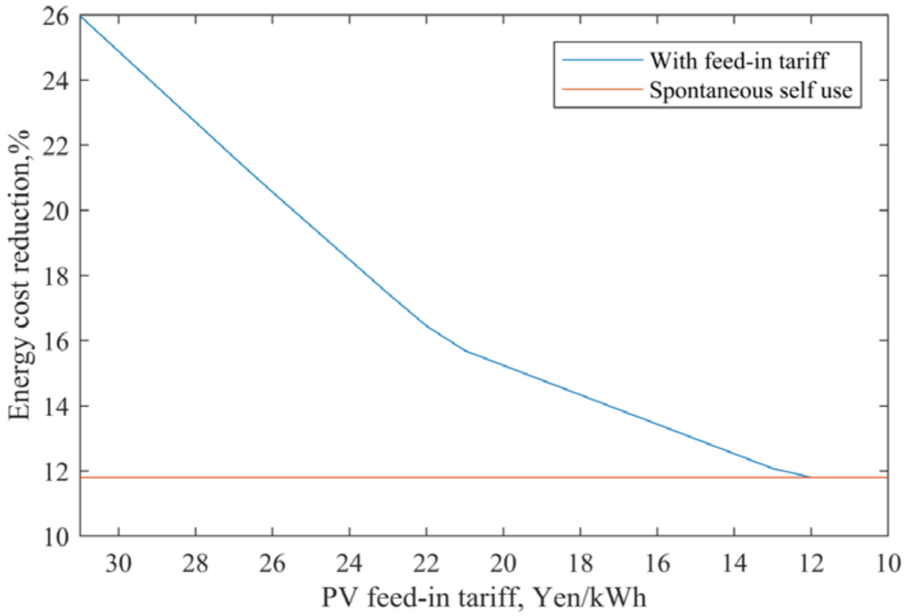

Figure 6-14 Comparison between with feed-in tariff and spontaneous self-use (cluster center 1, PV penetration rate 20%)

Referring to the daily electricity price in table 6-2, it shows that during weekends and holidays, the electricity price has been at the level of 9.06yen/kwh, resulting in the low average electricity yield of PV in the system of self use. On the contrary, when the PV is sold to the grid, the revenue of PV in this period of time has the largest decline space. Therefore, the adaptability of the six clustering centers to the demand side microgrid system will be reconsidered.

Figure 6-15 shows the minimum PV feed in price that can generate additional revenue. It can be seen that with the increase of PV penetration rate, the minimum feed-in-tariffs is constantly falling, that is, there is more room for reduction. Among them, cluster center 4 has the lowest tolerance to grid price, PV penetration fluctuates in the range of 2-20%, and the lowest feed-in-tariffs is 21-16 yen. Cluster center 5 has the highest tolerance to the feed-in-tariffs, which only needs 12 yen of minimum feed-in-tariffs at the beginning, and only needs 11 yen of minimum feed-in-tariffs when PV penetration exceeds 8%. This result is consistent with the light rejection analysis in Figure. 6-10. Therefore, when considering the policy of PV grid price, the results of adaptability to PV, battery and V2G system are contrary to those of self use, and cluster centers 1, 3 and 5 are selected.

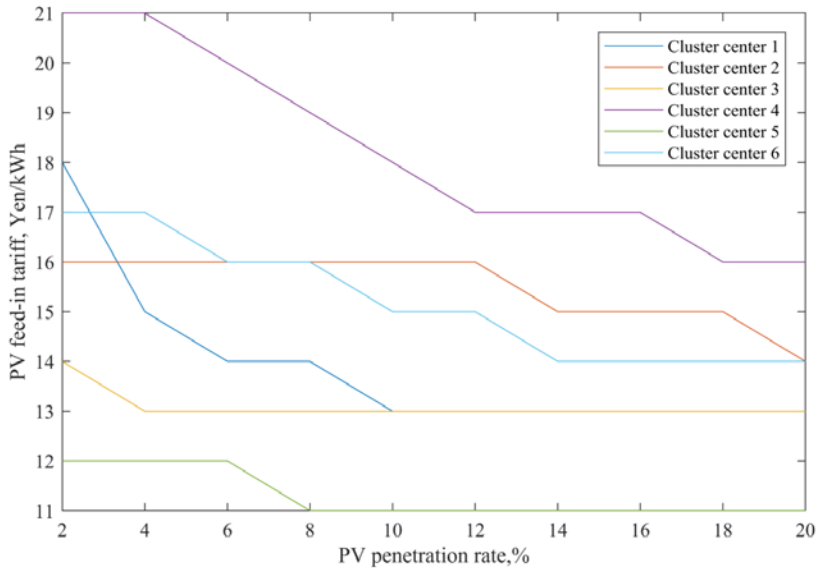

Figure 6-15 Minimum feed-in-tariffs under different PV penetration rates

6.4.3 Electricity free trade

According to the PV investment in table 6-3, it can be calculated that the cost price of PV is 7.1yen/kwh. This price is lower than the minimum feed-in-tariffs obtained in Figure 6-14, and the feed in price policy is still in the state of deficit expenditure. Therefore, when the distributed microgrid system is fully developed and promoted, the FIT policy will be reduced to below 7.1yen/kwh or close to the lower per kilowatt hour cost of large-scale PV stations. At this time, when the demand side can no longer generate additional revenue by selling surplus PV to the grid, it is considered to continue to increase the degree of liberalization on the demand side, allowing the surplus electricity to be traded with each other.

As the role of the battery is the storage of surplus PV and the handling of peak and valley electricity, the regional self-sufficiency rate cannot be improved. At the same time, in terms of the overall benefits of all buildings, the low price sales of battery electricity will cause the loss of overall economic benefits. Therefore, under the condition of ensuring the economic optimization of each building, it is not necessary to add additional batteries for sale to other buildings. The price of residual electricity transaction should not be higher than the daily electricity price, then the PV generation still gives priority to supply its own demand. Therefore, the main participants in the residual electricity transaction are the surplus electricity generated by PV power generation, and the electricity sales of buildings as aggregators of V2G services. At the same time, V2G service is not carried out on weekends and holidays due to the limitation of electricity purchase price from customers.

In order to be closer to the actual situation, different cluster centers are converted according to the total demand of load clustering. Table 6-4 shows the annual total load demand of the six clusters and the annual total load demand of the central point.

Table 6-4 Conversion ratio of different clusters

	Clusters 1	Clusters 2	Clusters 3	Clusters 4	Clusters 5	Clusters 6
Annual total load demand	7399.86	2409.13	6127.94	1188.51	3435.30	4762.56
Proportion of load demand, %	29.22	9.51	24.20	4.69	13.57	18.81
Annual total load demand of central point	38.81	15.95	31.57	26.03	61.70	25.12
Conversion ratio	1:190	1:151	1:194	1:46	1:56	1:190

After load conversion, the PV system is limited by the roof area, so the PV penetration rate is set at 10%. Combined with the relationship between V2G equipment and PV penetration rate in Figure. 6-10, it is considered that cluster 1, 3 and 5 are more suitable to participate in electricity trading as V2G service aggregators. Cluster 1, 3 and 5 are taken as the sales main body of V2G service, and the other buildings participate in the mutual transaction of surplus PV power generation, and three modes are obtained: power electricity free trade mode 1, electricity free trade mode 2 and electricity free trade mode 3. By comparing with the situation of self use and grid price of 20 yen / kWh, the overall regional energy cost reduction and power supply structure change are obtained as shown in Figures 6-16 and 6-17.

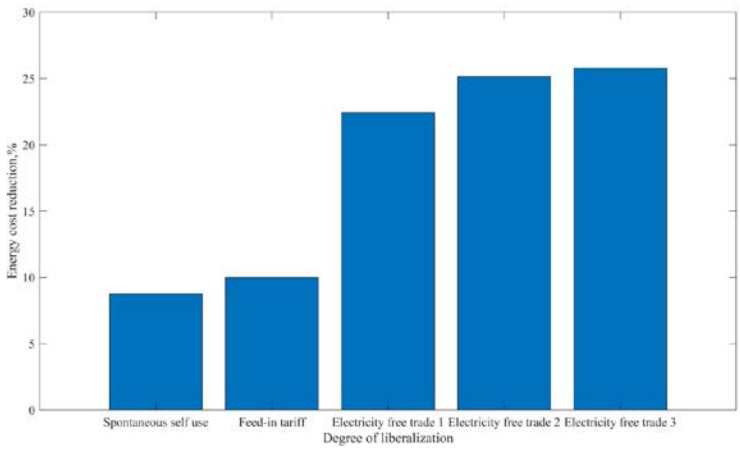

Figure 6-16 Comparison of economic benefits of microgrid with different degrees of liberalization on the demand side

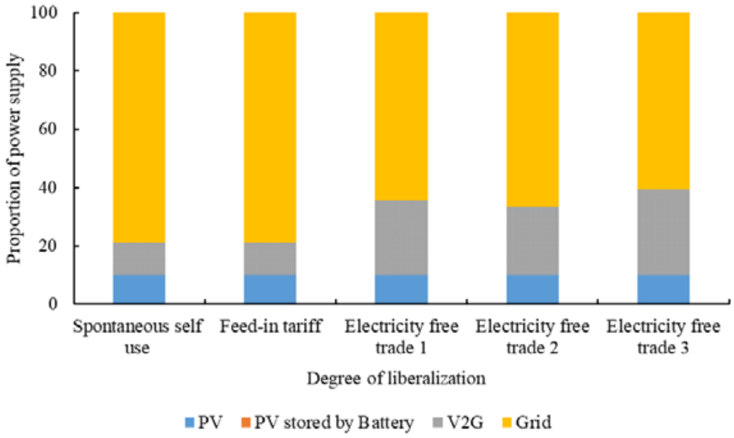

Figure 6-17 Comparison of energy supply structure with different degrees of liberalization on the demand side

As shown in Figure 6-16, the economic benefits of the electricity free trade have been significantly improved, and the third free trade mode has the best economic benefits. Combined with figure 6-17, it is concluded that the FIT policy can improve the economic benefits of the demand side. However, due to the small amount of discarded light, the transaction of surplus PV power generation has little change on the electricity supply structure, so it is not helpful to improve the supply rate. The mode of electricity free trade can effectively improve the participation of V2G, and increase the self-sufficiency rate of the whole region from 22% to 40% which has obvious effect. At the same time, the increase of V2G electricity supply also brings about the improvement of economic benefits, and the overall economic benefits increase by 22-25%. Among them, electricity free trade mode 1 has a higher self-sufficiency rate, but its economic benefits are relatively low. Electricity free trade mode 3 has the highest self-sufficiency rate and economic benefits. Therefore, in the target area, the office buildings represented by cluster 5 are the most suitable aggregators for V2G services under the electricity free trade mode.

6.5. Summary

The research on the configuration and adaptability of demand side microgrid under mixed load and different degrees of liberalization has a high practical value. This study studied the optimization of the system configuration under the influence of V2G technology introduction, demand side liberalization degree change and different load types by modeling the micro grid system of Higashida smart community in kitakushu, Japan. Firstly, 49 buildings in the target area were selected, and the buildings were divided into six clusters by factor analysis and cluster analysis. The load adaptability was studied by the cluster center point. Then, through Monte Carlo simulation of the vehicle visit status and dwell time, the maximum allowable discharge capacity of the EV participating in V2G service was obtained. Then, the configuration optimization of micro grid system composed of photovoltaic, battery and V2G was carried out through the setting of three demand side liberalization scenarios, namely, spontaneous self-use, photovoltaic feed-in tariff, and electricity free trade. Finally, the load adaptability research results were obtained by comparing with the load characteristics:

(1) In the case of spontaneous self-use, only cluster 5 which has the gentlest load changes in office buildings was suitable for V2G technology. At the same time, the improvement of PV permeability caused the economic benefit of V2G technology to decrease, and the self-sufficiency rate decrease greatly. Therefore, cluster 3 (shopping mall building) which can maintain the self-sufficiency rate within 23% - 24% was obtained to be the most suitable for the promotion of demand side micro grid system.

(2) In the case of PV feed-in tariff, because the demand side had the flexible processing capacity for photovoltaic power generation, and the inhibition effect of photovoltaic on V2G technology had been relieved, so clustering 1,3 and 5 which were more suitable for V2G technology had high economic benefits. Among them, cluster 5, which represented the gentlest load change, had the highest tolerance to the feed-in tariff, and could still generate the income from selling electricity when the feed-in tariff reduced to only 11-12yen/kwh.

(3) In the case of electricity free trade, V2G technology could be expanded by aggregator transaction. Through the comparative analysis of cluster 1,3 and 5, it was found that cluster 5 can generate the highest economic benefits of 25% as aggregator of V2G, and the self-sufficiency rate of the whole region can reach 40%.

In summary, when the demand side freedom is low, the dominant equipment of the microgrid is photovoltaic, so the shopping mall buildings with large load gap between day and night and load in line with the photovoltaic power generation law have higher adaptability. When the demand side freedom is high, the core of the micro grid is gradually transferred to V2G technology, so office buildings with gentle load change and more V2G power generation capacity have higher adaptability.

This paper compared and analyzed the adaptability of microgrid system under different demand side liberalization. The actual reference value of the results is high. However, only the local actual peak and valley price was used as the research basis, so there is still room for further improvement in sensitivity analysis of energy price and equipment cost.

Appendix

Table A-1 Building classification and load characteristics

Number	Building type	Total power load	Average load	Load standard deviation	Coefficient of Variation
1	Convenience Store	16623583	1897.67	383.91	0.20
2	Convenience Store	2769357	316.14	93.28	0.30
3	Convenience Store	4184862	477.72	79.60	0.17
4	Experimental building	1414719	161.50	76.54	0.47
5	Experimental building	1970511	224.94	240.34	1.07
6	Experimental building	507839	57.97	57.16	0.99
7	Factory	2424430	276.76	163.87	0.59
8	Factory	4114748	469.72	564.12	1.20
9	Factory	4084145	466.23	227.12	0.49
10	Factory	676765	77.26	68.99	0.89
11	Factory	1543672	176.22	182.03	1.03
12	Factory	3726586	425.41	324.37	0.76
13	Gas station	4528090	516.91	248.48	0.48
14	Hospital	2998625	342.31	117.48	0.34
15	Hospital	8149480	930.31	344.51	0.37
16	Hotel	9077146	1036.20	312.67	0.30
17	Museum	6092870	695.53	506.36	0.73
18	Museum	3070921	350.56	318.47	0.91
19	Office	13840946	1580.02	610.17	0.39
20	Office	2695903	307.75	289.70	0.94
21	Office	1270194	145.00	247.77	1.71
22	Office	3050399	348.22	335.88	0.96
23	Office	1069522	122.09	108.30	0.89
24	Office	524032	59.82	35.66	0.60
25	Office	10725381	1224.36	176.77	0.14
26	Office	19442785	2219.50	121.85	0.05
27	Office	720871	82.29	75.69	0.92
28	Office	1906265	217.61	108.86	0.50
29	Office	4098596	467.88	282.94	0.60

30	Office	1625543	185.56	116.03	0.63
31	Office	2010132	229.47	154.27	0.67
32	Office	1864595	212.85	117.23	0.55
33	Office	10307210	1176.62	580.47	0.49
34	Office	2885694	329.42	340.07	1.03
35	Office	4194601	478.84	307.72	0.64
36	Railway platform	4855896	554.33	132.74	0.24
37	Railway platform	3866207	441.35	226.35	0.51
38	Residential	8769564	1001.09	428.51	0.43
39	Residential	2385953	272.37	67.75	0.25
40	Shopping	12883259	1470.69	1065.77	0.72
41	Shopping	7709812	880.12	814.88	0.93
42	Shopping	2317868	264.60	280.22	1.06
43	Shopping	5737262	654.94	431.76	0.66
44	Shopping	4438354	506.66	432.99	0.85
45	Shopping	6627849	756.60	630.98	0.83
46	Shopping	5128161	585.41	389.89	0.67
47	Shopping	16436830	1876.35	1095.03	0.58
48	Shopping	8312497	948.92	1045.70	1.10
49	Shopping	3572621	407.83	276.29	0.68

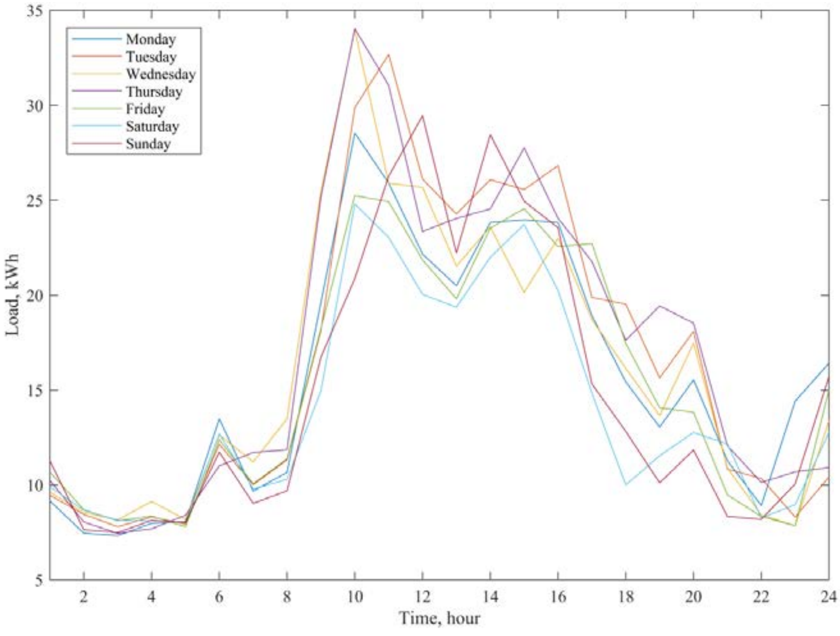

Figure B-1 Typical weekly daily load change of cluster center 2

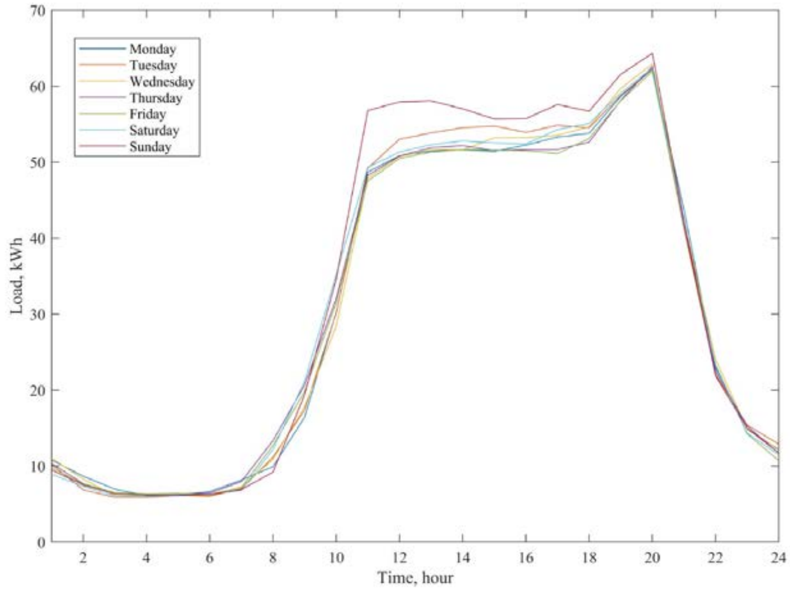

Figure B-2 Typical weekly daily load change of cluster center 3

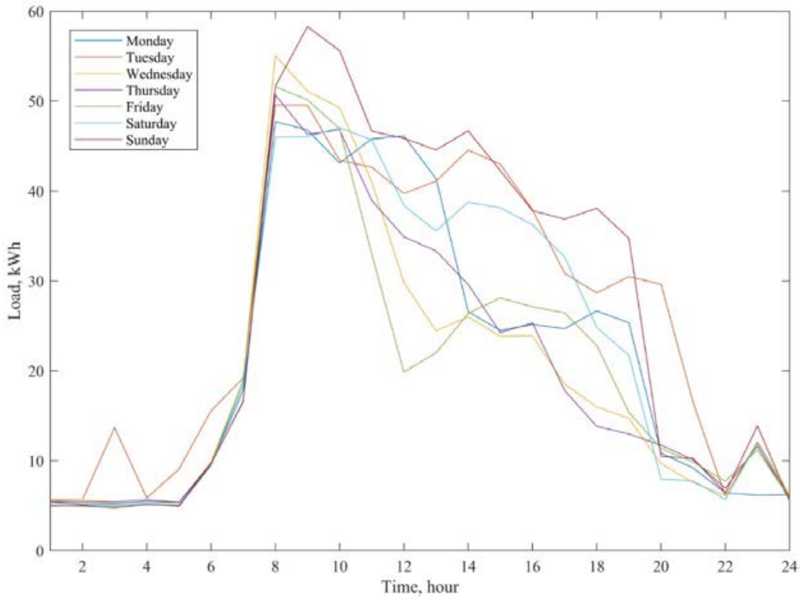

Figure B-3 Typical weekly daily load change of cluster center 4

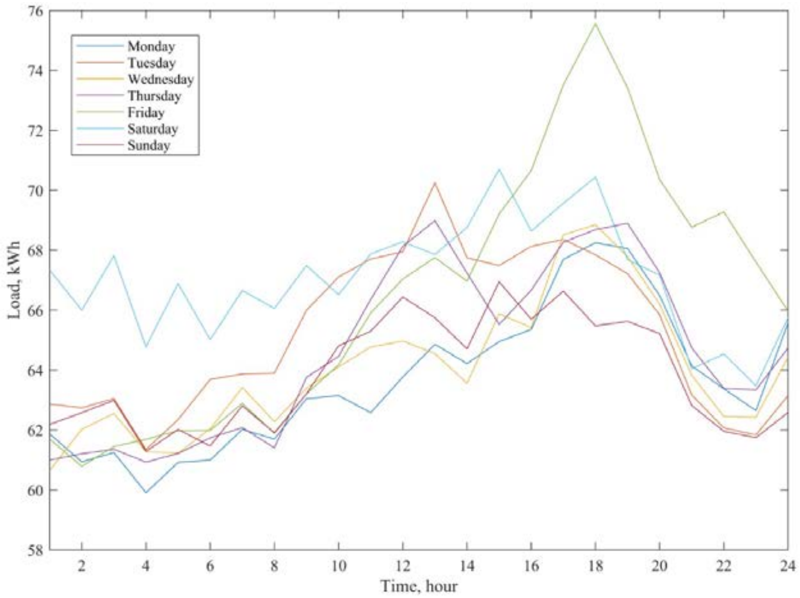

Figure B-4 Typical weekly daily load change of cluster center 5

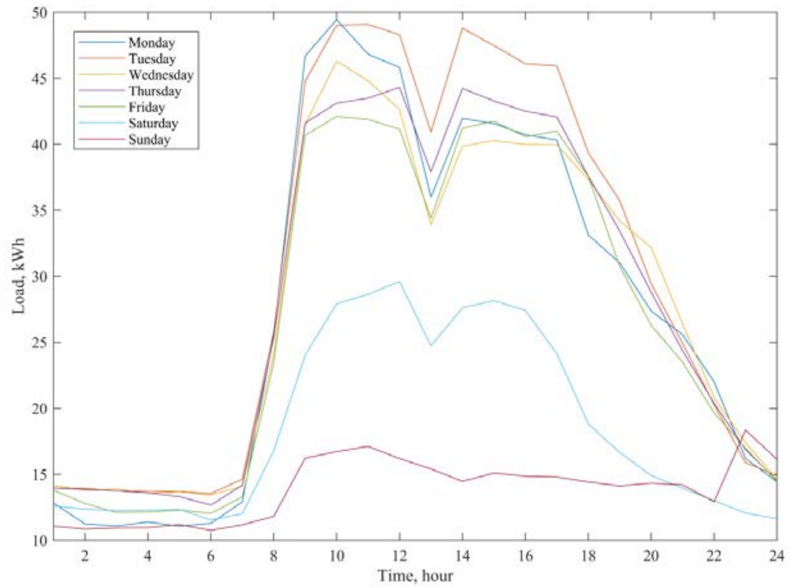

Figure B-5 Typical weekly daily load change of cluster center 6

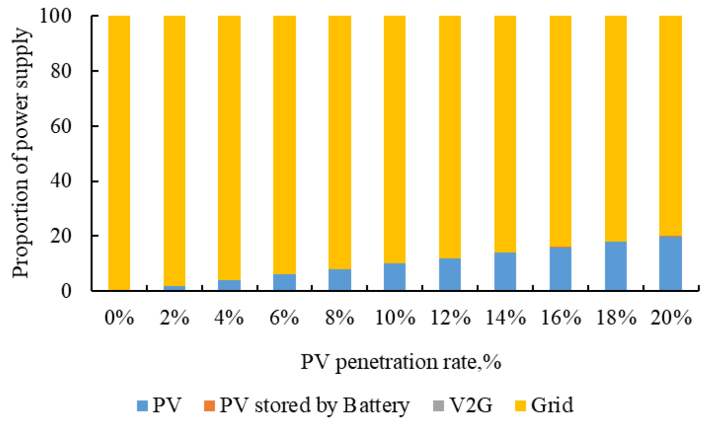

Figure B-6 Change of energy supply structure with PV penetration (cluster center 2, museum, experimental and office buildings)

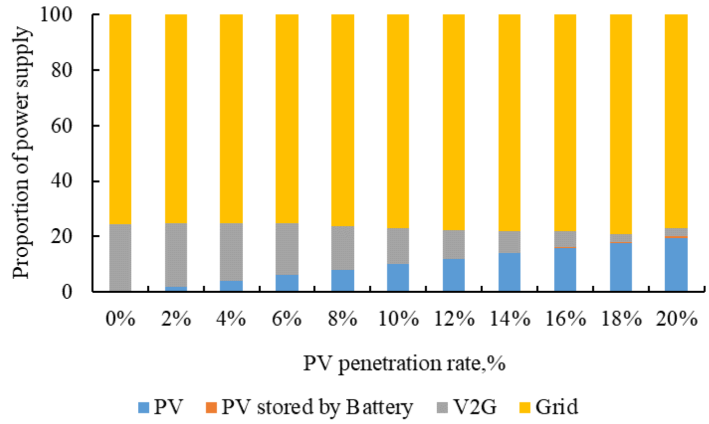

Figure B-7 Change of energy supply structure with PV penetration (cluster center 3, commercial buildings)

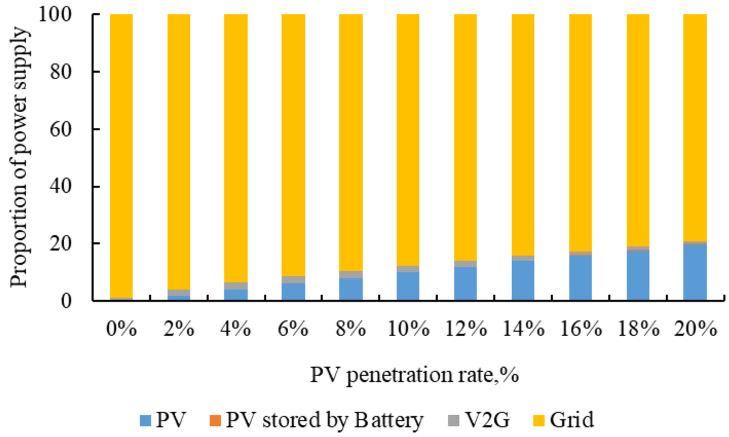

Figure B-8 change of energy supply structure with PV penetration (cluster center 4, commercial buildings)

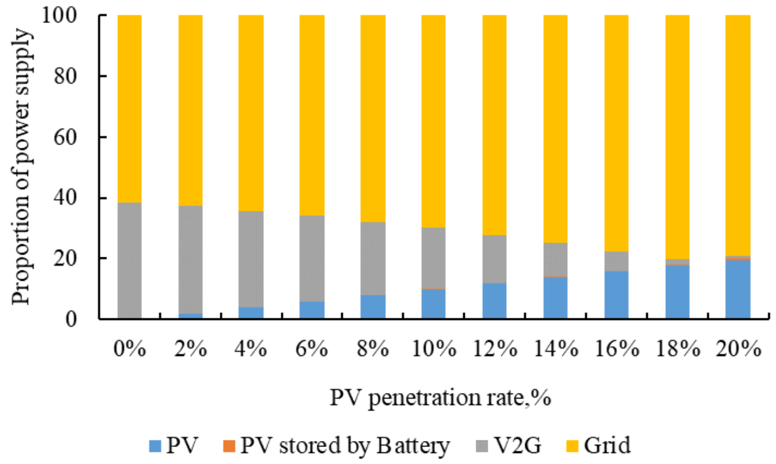

Figure B-9 Change of energy supply structure with photovoltaic penetration rate (cluster center 5, office building)

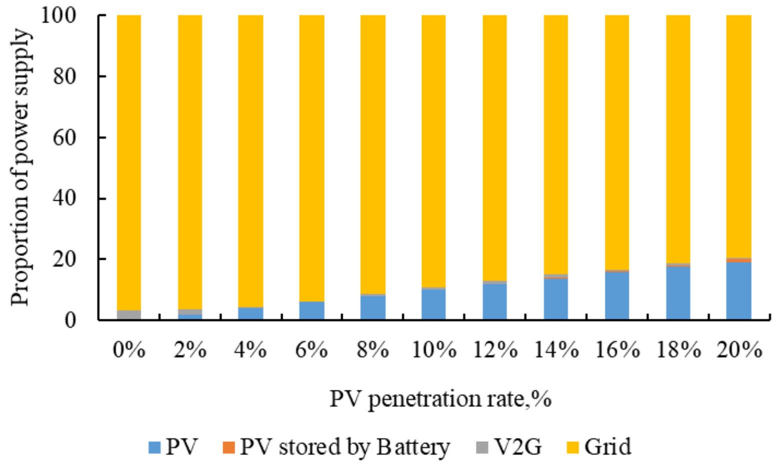

Figure B-10 Energy supply structure changes with PV penetration (cluster center 6, office and factory buildings)

Reference

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Chapter 7

DISCUSSION, CONCLUSION AND PROSPECT

CHAPTER SEVEN: DISCUSSION, CONCLUSION AND PROSPECT

7.1 Discussion

The technical and economic means of DSM can effectively reduce the user demand and smooth the load curve, thus reducing the power supply pressure of the power grid. To this end, countries all over the world have launched a variety of demand side management promotion policies. However, due to the complexity of data collection and analysis of multiple energy sources and the variability of the objective environment, most of the policies cannot be specifically analyzed, and even a variety of policies cannot be clearly identified and distinguished due to overlapping functions. At the same time, under the background of the gradual transformation of the energy system, new energy types and utilization methods are constantly emerging. The application of new energy vehicles and machine learning also brings a new development direction for demand side management. Therefore, this study proposed to take Japan as an example to evaluate the promotion effect and development potential of demand side energy-saving technology from two aspects: the effect of existing policies and the development potential of new policies. This paper analyzed the technology side means of DSM from three aspects: the policy of equipment energy efficiency improvement, the impact of retail electricity price in electricity market and demand side adaptability. After combing and integrating the analysis results of each chapter, this paper discussed the terminal energy efficiency improvement and user load adjustment of DSM technology side means

In terms of terminal energy efficiency improvement, the analysis showed that Japan's "top runner" system has a poor effect on energy consumption and carbon emissions of residential buildings with poor regularity, but has a higher effect on commercial office buildings with strong regularity. The reason mainly comes from the irregularity of users' energy consumption behavior and the rebound effect brought by the improvement of equipment energy efficiency. Among them, the rebound effect of air conditioning equipment is the lowest, and the energy efficiency of equipment is the best, which is more worthy of investment in technology research and development. Although from the existing data analysis or from the long-term perspective of the whole life cycle, the energy efficiency improvement effect of lighting equipment is the weakest, but due to the high energy consumption of its own lighting equipment, LED equipment still has a good potential for improvement.

In the aspect of user load adjustment, electricity price regulation was particularly critical, especially for the adjustment of time of use price peak valley gap, which has a huge impact on the establishment of distributed energy system on the user side. At the same time, according to different demand side load characteristics, equipment selection should be differentiated. In the social environment of more and more liberalization of power market, the adaptability of users with gentle load change to distributed energy will gradually decrease. It is suggested that more attention should be paid to energy saving of their own equipment, or more accurate load forecasting should be used to participate in the day ahead trading market of the power market as the buyer. For users with obvious load change and strong regularity, it is suggested to build a larger capacity of distributed energy equipment as the seller to participate in the electricity market transactions. Among them, building as the aggregator of electric vehicle V2G technology has high practical value and economic potential.

7.2 Conclusion

The main works and results can be summarized as follows:

In chapter one, RESEARCH BACKGROUND AND PURPOSE OF THE STUDY, analyzed the demand growth and energy structure changes in the current global energy transformation stage, highlights the importance of demand side management, and expounds the specific implementation of DSM from the technical side and economic side. At the same time, this part focused on the two development hotspots of DSM: distributed energy and electricity market liberalization, and systematically explains the development status of DSM, the development of energy-saving technology, energy efficiency promotion policy, renewable energy subsidy system and the promotion of power market. Finally, the purpose, logic, content and internal relevance of the research were described.

In chapter two, DEVELOPMENT PROCESS AND RESEARCH STATUS OF DEMAND SIDE MANAGEMENT (DSM), summarized the development path of demand side management in representative countries, and reviewed the research status of demand side management technology and economic means, such as changing demand side load, improving equipment energy efficiency, price based and incentive-based user response. This part focused on the research on distributed energy and electricity market liberalization. At the same time, the application of machine learning, blockchain technology, Internet of things and other computer and Internet technologies in demand side management were described.

In chapter three, TECHNICAL SIDE EQUIPMENT MODELING AND ECONOMIC SIDE THEORETICAL DERIVATION, is about methodological research and model building, firstly, the load characteristics of demand side were analyzed, and the variation characteristics of different types of loads were studied. Then, the characteristics of typical energy consumption and energy supply equipment on demand side were studied and modeled. Next, the economic means in DSM were sorted out, including the electricity price model and the reward and punishment mechanism. Finally, the demand side management strategy based on dynamic reward and punishment mechanism and real-time price was proposed, and the theoretical derivation was carried out.。

In chapter four, THE PROMOTION ANALYSIS OF POLICIES ON THE TECHNICAL SIDE OF DSM, the basic energy and environmental data of Japan such as primary energy consumption, carbon emission and GDP were collected, and the important role of the demand side on the overall social energy conservation and emission reduction work was obtained through the factor decomposition model. After that, Japan's equipment energy promotion policy "Top Runner" was identified and its effect was analyzed. It was found that the promotion effect in commercial office is the most obvious. Finally, the rebound effect of energy efficiency improvement of typical equipment was analyzed from three aspects: the use stage, the whole production scrap stage and the whole life cycle stage. The results show that the air conditioning system has the highest energy saving potential.

In chapter five, THE EFFECT ANALYSIS OF ELECTRICITY PRICE ON THE TECHNICAL SIDE OF DSM, analyzed the effect of demand side management (DSM) price model change. Firstly, through the curve fitting and correlation analysis of annual average retail and wholesale electricity prices, it was concluded that the impact of power market liberalization on demand side retail price is high. Then, the volatility of wholesale electricity price was studied by moving window and artificial neural network prediction. The results showed that with the continuous expansion of the power market scale, the power demand and the wholesale price show a strong correlation. Next, with the energy consumption simulation of residential buildings, the impact of different electricity price modes on typical energy consumption equipment was studied. It was found that although lighting equipment has the best effect in the mixed electricity price mode, once the rebound effect of users is considered, only led has the development potential of energy efficiency improvement. Finally, based on the adaptability of energy storage battery system to TOU price, the influence of different peak valley gap was studied. The results showed that only 2.5% of the current peak price can make the battery lose economic benefits. At the same time, 150% increase in peak gap can bring more than 4 times of economic benefits for the battery, the effect is obvious.

In chapter six, ANALYSIS OF DEMAND SIDE ADAPTABILITY UNDER THE JOINT ACTION OF TECHNOLOGY AND ECONOMIC MEANS, the adaptability of demand side distributed energy system with different characteristics was analyzed. Firstly, 49 buildings in Higashida area of Kitakyushu city were selected as the research object. Through factor analysis and cluster analysis, the dimension of the research object was reduced, and six clustering and clustering centers were obtained. Then photovoltaic, battery and electric vehicle V2G were selected as the components of distributed energy system, and the optimal configuration of six clusters under three modes of self-use, photovoltaic feed-in traffic and free trade were studied, respectively. The results showed that the self-sufficiency rate of office buildings with gentle load change is the highest under the scenario of spontaneous self-use, which is also the most suitable for the application of hybrid energy system. In the other two modes, the shopping malls with obvious load difference between day and night and strong regularity throughout the year are the most suitable to promote hybrid energy system and can participate in the electricity trading as load aggregators.

In chapter seven, DISCUSSION, CONCLUSION AND PROSPECT, have been presented.

Generally speaking, this study studied the effect, influence and trend of DSM technology side means from three aspects of national policy, regional electricity price and demand side load characteristics.

From the perspective of national policy, the implementation effect of "Top Runner" of equipment energy efficiency improvement policy in Japan is obvious, among which the policy benefits of commercial office equipment and air conditioning equipment are the highest.

From the perspective of regional electricity price, the competition of small power retailers promotes the decline of demand side price. It is helpful to improve the economic benefits of energy-saving equipment through the differentiation of electricity price mode and the widening of the gap between peak and valley of TOU price.

From the perspective of demand side load characteristics, the closed trading environment gives rise to the demand side load leveling of distributed energy system, while the open trading environment can make distributed energy equipment truly realize the role of relieving the pressure of power grid.

7.3 Prospect

For prospect, the economic side means of demand side management has not been studied in depth. Due to the lack of reference objects and data, the implementation of reward and punishment mechanism and real-time price is only theoretically deduced, but not verified by actual cases. According to the results of the research and analysis, the more mature the development of the electricity price model, the better the promotion effect of the demand side technical means. Therefore, it is considered that the research on the real-time price and the reward and punishment mechanism has a great space for further research on the promotion of the technical means.

In addition, in the study of demand side distributed energy system, only the power supply is considered, and the possibility of cold and hot supply is not considered. The reason is that most of the cases with heat and cold data are regional buildings with composite characteristics, and rarely cover all types of buildings, so it is impossible to conduct comparative study. Therefore, continuous data collection and analysis are also needed in this aspect.

At the same time, although the rebound effect of demand side is calculated, there is no in-depth study on the analysis of user behavior characteristics. In fact, the identification and prediction of user behavior is also an important part of demand side management, which has high research value.