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ARTICLE

Technical System Construction in the Market Trading System for Demand Response Based on the Energy Internet

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ABSTRACT

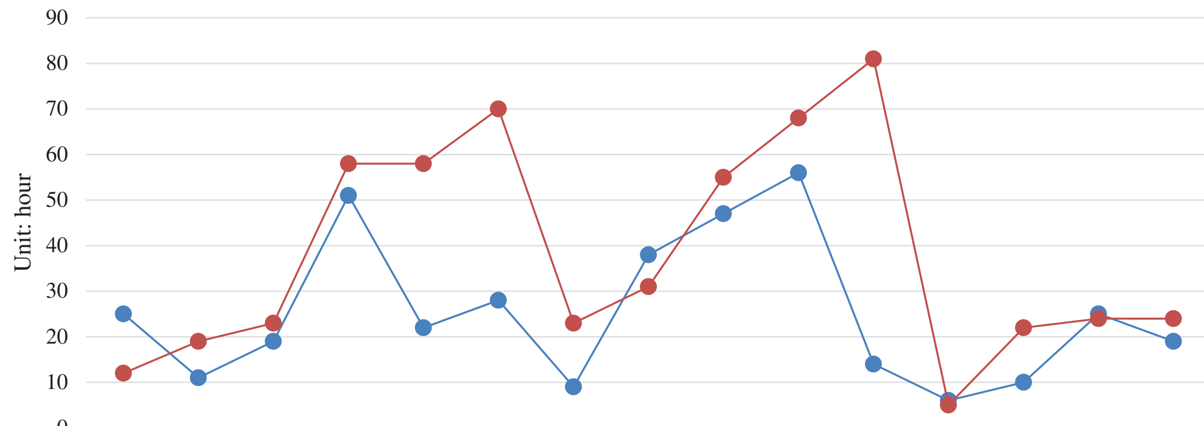
With the explosive growth of variable renewable energy, the balance between the supply and demand of the power grid is faced with new challenges. Based on the development experience from typical countries and the state quo in China, this paper further analyzes the system architecture and development trend of demand response under the background of Energy Internet. Five dimensions are considered: Energy Internet platform, demand response application scenarios, system architecture, information technology system construction, and demand response development trend. The results show that the application of the Energy Internet platform can effectively solve the problems of data acquisition and processing, "terminal-edge-network-cloud" cooperation of demand response, etc. The system architecture of the demand response platform that supports user resource management, user information access, control instruction receiving, control strategy issuing, and response process monitoring is proposed in this paper. It is also helpful to provide a feasible technical choice for expanding the application services of Energy Internet towards government and society.

KEYWORDS

Balance of supply and demand; energy internet; demand response; market trading system; technical system construction

1 Introduction

In recent years, the contradiction between the supply and demand of the power grid has become increasingly prominent in China [1]. On the one hand, the seasonal peak load contradiction is prominent. With the continuous improvement of the electrification level, the influence of weather factors on electricity load and electricity consumption has become more obvious. The phenomenon of peak power supply tension with seasonal and regional characteristics has become a nationwide problem in China. Although the peak load has increased, its duration has decreased. According to statistics, the utilization hours of the peak load with the highest load over 95% in 2018 are only from 5–81 h (see Fig. 1), and the corresponding electricity consumption does not exceed 5‰ of the annual electricity consumption in the "North China, East China, and Central China" area. If a peaking power plant is built through investment, then the investment scale of the relevant power plant and supporting power grid is approximately 285 billion yuan, which will lead to a great waste of social resources.



	Hebei	Beijing	Shanxi	Shandong	Jibei	Tianjin	Anhui	Shanghai	Jiangsu	Zhejiang	Fujian	Jiangxi	Henan	Hubei	Hunan
2017	25	11	19	51	22	28	9	38	47	56	14	6	10	25	19
2018	12	19	23	58	58	70	23	31	55	68	81	5	22	24	24

Figure 1: Over 95% load utilization hours in all provinces in the "north China, east China, and central China" area

On the other hand, as the installed capacity of new energy continues to grow, the contradictions among the demand for new energy delivery, the operation mode of the power grid, and the limited capacity of the delivery channel become increasingly prominent. The compensation mechanism for superimposing new energy and conventional power supply is still not perfect, resulting in the severe situation of new energy consumption [2]. The peak regulating pressure of the power grid continues to increase. Under the requirements for supply-side structural reform, cost reduction, and efficiency-enhancement, it is difficult for the traditional measures such as building new peak shifting units or transmission and distribution networks to solve the above problems economically and efficiently. In this study, the construction of a demand response (DR) operation system based on the Energy Internet is conducive to the rapid development of market-oriented demand response and to solving the contradiction between the supply and demand of power grids.

Compared with some developed countries, China's demand response developed relatively late. Many scholars have conducted studies on the implementation and development of demand response in developed countries. Zhang et al. [3] classified the existing problems and particularly pointed out the problems of information security protection starting with the information security threats faced by the Energy Internet. Feng et al. [4] analyzed the environments of "Energy + Internet" development and discussed social-economic changes brought by it. Tahir et al. [5] and Liu et al. [6] compared and analyzed the differences between the demand response of developed countries and China in terms of policies, demonstration projects, implementation effects, and standards. They noted that policies and industry standards should be improved to actively explore ways for allowing the demand response to enter the electricity market. Albadi et al. [7] and Larsen et al. [8] noted that China's demand response needs more policy support, more publicity on the user side, and more combination of technology with the smart grid and other modern technologies based on a summary of the development process and existing implementation plans of demand response in the United States and the European Union. Alasseri et al. [9] and Lu et al. [10] noted that the entry of demand response into the electricity market can bring economic, environmental, energy, and other benefits to those participating in the demand response and the power system. In practice, different types of demand response should be implemented in combination with regional characteristics. In addition to the further improvement of policies and regulations, some scholars believed that the business model suitable for the development of China's demand response should also be explored according to the current situation of China's electricity market. Torbaghan et al. [11] noted that China's demand response has not been integrated with the electricity market, and the lack of business modes will hinder the development of the demand response in China. Based on the development practice of the demand response in the PJM market in the United States, it was noted that China can gradually introduce different demand response items from the electric energy market and the auxiliary service market and, finally, realize joint optimal scheduling of power generation, standby and frequency modulation. Pinson et al. [12] put forward that China's demand response should evolve from administration to marketization and continue to explore new modes of user-side demand response based on the time characteristics of incentive and price demand response in the United States and the European Union. At the same time, the existing information and communication means should be combined to promote the implementation of demand response on a smaller time scale. Wu et al. [13] introduced the ability of consumer-centered Energy Internet and expounded the definition of Energy Internet from the characteristics of digitalization and decentralization. But these researches have failed to deeply explore the relationship between demand response and Energy Internet.

Most existing studies put forward the future development direction according to the current development situation of demand response. Therefore, the market-oriented development of demand response in the context of Energy Internet should be further discussed on this basis. The innovations of this study are mainly reflected in the following aspects:

(1) Based on the construction of the Energy Internet and foreign development experience, the gaps in China's demand response business pilot, policies and regulations, technical standards, and other aspects are analyzed in depth.
(2) The important influence of the operating mechanism and the technical characteristics of Energy Internet on the way to implementing demand response is analyzed. Based on this analysis, the market development requirements of demand response are considered from the aspects of effect evaluation, data monitoring, response execution, market strategy, and demand regulation. A market-oriented information technology system for demand response based on the Energy Internet platform is constructed, aiming to form a practical adjustable load participating power grid regulation mechanism to ensure the safe and economic operation of the power grid.
(3) The information technology system construction contents of the system side, load side, and load aggregators in the demand response system are proposed.
(4) The development trend of the future demand response is analyzed from five aspects, including response mode synthesis, implementation subject diversification, operation mechanism marketization, system decision intelligentization, and execution mode automation.
(5) Based on the analysis of the future development trend of demand response, this study puts forward recommendations for the development of integrated demand response and future policy requirements under the Energy Internet.

The rest of the study is organized as follows. Section 2 summarizes the development experience of typical countries and the development situation of China in the field of demand response. According to the application scenario analysis of the Energy Internet platform and demand response, Section 3 constructs the demand response system architecture based on Energy Internet and proposes contents of information technology system, and describes the development trend of demand response in the future.

Section 4 concludes and proposes policy recommendations for the development of integrated demand response in the context of the Energy Internet.

2 Market-Oriented Trading System for Demand Response

2.1 State quo in Typical Counties or Regions

The development status of the market-oriented trading system for demand response in typical countries or regions such as the United States, European Union, and Japan is analyzed from policy supports, fund sources, and control methods.

(1) Policy supports

To promote the smooth development of demand response, the United States has issued supportive policies for the development of demand response since 1992. Demand response resources can compete with power generation resources to participate in the wholesale market and provide various services, including energy, capacity, and auxiliary services. In 2011, the Federal Energy Regulatory Commission stated that demand response could be a cost-effective option for balancing energy supply and demand and required corresponding compensation [14]. In 2016, demand response was listed as a plus item in the "Leadership in Energy and Environmental Design" that is conducive to fully tapping the value of demand response resources and improving the operating efficiency of the power system. The European Union's "Energy Efficiency Directive" stipulates that member states should adopt incentives to ensure demand response participation in the balanced market and ancillary services and continuously increase consumer participation for improving system efficiency. At the same time, it is noted that consumers can enter the energy market individually or through aggregators and that member states should ensure that national regulatory agencies encourage demand-side resources to participate in the wholesale and retail markets. France has enacted laws to allow demand response to participate in the energy market as a third party. Japan proposed a new development model of demand response in the Fourth Energy Basic Plan to strengthen user demand management and ensure stable power operation [15]. Subsequently, the "Japan Rejuvenation Strategy" proposed to achieve the goal of demand response accounting for 6% of the total electricity demand by 2030. Besides, Japan has formulated a government subsidy plan from 2016 to 2020 in its "Energy Innovation Strategy" to support enterprises in developing demand-response technologies and plans to launch the capacity market in 2020 to create a demand-regulating market.

(2) Fund sources

From 2013 to 2017, the United States accumulatively subsidized approximately eight billion U.S. dollars in demand response incentive funds. More than twenty states have implemented a system benefit charging system, charging an additional 1%–3% of electricity prices for demand-side management. In Europe, demand response suppliers can bid on power exchanges and use marginal prices for settlement. France established a demand-side resource reserve that can balance the power market. In 2015, France introduced a capacity compensation mechanism in which integration service providers can participate and get paid. French transmission companies can issue capacity certificates to demand response integration service providers to reduce electricity demand. Starting from January 01, 2017, demand response can enter the intraday market for bidding. From 2016 to 2017, Japan issued nearly nine billion yen in subsidies for seven virtual power plant demonstration projects. As of the end of 2018, there were nearly six hundred electricity sales companies in Japan, accounting for approximately 15% of electricity sales. Electricity users can independently choose electricity sales companies and can directly participate in market-oriented demand response transactions. At present, Japan has established a market operation mechanism based on the participation of demand resources in the multi-level time scale market. Power companies sign demand response execution contracts with users, and the discount amount for users to perform demand response will be deducted from the monthly charges.

(3) Control methods

The United States has nearly 40 gigawatts of demand-response resource capacity in the four sectors of industry, commerce, household, and transportation. First, the direct load control method can be used. The plan initiator can remotely shut down or periodically control electrical equipment, such as air conditioners, after notifying the user. Second, the interruption or reduction method can be applied to provide rewards or compensation, respectively, based on the user's willingness. Finally, the emergency demand response method can be adopted. This method is suitable for users who voluntarily reduce their electricity consumption under special circumstances, which is generally achieved by providing users with an incentive compensation of the amount and level agreed upon in advance. Over the past ten years, emergency demand response has been adopted at a large scale in the US wholesale market.

In France, load aggregators are mainly used. Load aggregators participate by bidding in the trading market and then sign contracts with operators to participate in demand response. The control mode mainly includes automatic control and manual control of a continuous trigger, and the trigger of manual control has no time limit. The frequency of the French power grid dropped from the rated frequency of 50 Hz to below 49.82 Hz on January 10, 2019. To ensure the safe and stable operation of the system, the French electricity transport company urgently used the low-frequency load shedding demand response and cut off 1.5 GW of interruptible load via direct control of the interruptible load.

In Japan, invitation and real-time are the two main methods for controlling demand-response resource capacity, and the invitation is dominant. The resources involved in regulation can be divided into two categories. Type I resource-based services are charged capacity and electricity use fees at the same time unless exempted by network operators; Type II resource-based services only charge the electricity usage fee but are not subject to other requirements. Type I resources can be further subdivided into real-time Type I-a balanced resources and Type I-b balanced resources. Among these, real-time Type I-a balanced resources includes Type I balanced resources in extreme cases, frequency modulation services, etc. Type I-b balanced resources do not include frequency modulation services.

2.2 State quo in China

Compared with countries and regions with better-developed demand response businesses, such as Europe and America, China still has a gap in terms of the demand response business pilot, policies and regulations, technical standards, and so on.

(1) In China, the development of the demand response business is not balanced among the provinces and cities, and the gap among them is large. Only six provincial and municipal companies in the load center area have carried out demand response pilot projects.

(2) The construction of demand-side mobile peak shaving capacity has not yet met the requirements of national policies and regulations. According to the "Revised Power Demand Side Management Methods", the demand side peak load regulation capacity should account for approximately 3% of the annual maximum power load, but in reality, only the State Grid Jiangsu Electric Power Co., Ltd., China of all the provinces and cities has achieved this target.

(3) The construction quality and market operation of demand response projects need to be strengthened. In designing pilot programs, purchasing software and hardware equipment, project construction, and business implementation, not all provinces and cities strictly followed the current national

and industry standards for implementation, resulting in a high level of investment in capacity building in response to resource peaking per kilowatt.

(4) The demand response business development technology needs to be improved, as mainly reflected in the lack of theoretical methods, the unclear response mechanism for flexible resource participation in demand response, and the incomplete simulation model. The model seldom involves the supply and demand interaction of large-scale flexible resources and less frequently considers the optimal configuration and operation of large-scale flexible resources and friendly connections between the control strategy and grid operation control. The deep integration of edge computing, blockchain, and other emerging technologies with demand response services needs to be strengthened.

(5) The demand response policy mechanism needs to be further improved. The relevant policies of the national and provincial and municipal governments are not yet perfect, and it is difficult to normalize and scale them. Currently, only some of the policies issued at the national level that guide the development of demand response have been implemented, and most provinces have not yet issued practical demand response subsidy policies.

(6) User acceptance and participation in demand response need to be improved. Power users have low awareness and acceptance of demand response, and their subjective willingness to participate in power demand response is not strong. It is necessary to strengthen the publicity of the comprehensive benefits of demand response and popularize the basic knowledge of power users on the participation benefits and participation methods of demand response. At the same time, it is necessary to integrate "Internet +" thinking to innovate market-oriented interaction methods and incentive strategies for power users to participate in demand response.

3 System Architecture and Development Trend for Demand Response in China

Based on the comparative analysis of demand response technologies between China and typical countries, the system architecture and development trend of demand response under the Energy Internet are comprehensively discussed.

3.1 Energy Internet Platform

With the implementation of a new scientific and technological revolution, advanced information and communication technologies, as represented by big data, edge computing, cloud platforms, etc., promote the deep integration of Internet technology and the energy industry. Energy Internet, as an industrial Internet applied to the energy industry, is a new form of energy industry development that deeply integrates the Internet with energy production, transmission, storage, consumption, and the energy market. Energy Internet has the basic characteristics of mutual integration and two-way transmission for energy flow and information flow [16,17]. Energy Internet has achieved horizontal "multi-energy complementation", which can realize complementary coordination among various energy and resource systems. At the same time, Energy Internet achieves vertical "supply-network-load-storage", which can realize the development and utilization of energy resources as well as coordination among the resource transportation network, energy transmission network, and energy consumption. Energy Internet is of great significance for adjusting China's energy structure and forming new demand-side management methods [18,19]. The basic architecture of the Energy Internet is shown in Fig. 2.

3.2 Application Scenario Analysis of Demand Response

The efficient information interaction system constructed by the Energy Internet is conducive to improving the level of refinement of demand-side management and the level of personalized service of users' energy use.

In terms of residential electricity consumption, the electricity information acquisition system can mine data, provide support for accessing metered information such as various energy sources and electric vehicles, provide value-added information services for the two-way interaction between supply and demand, and form a service network covering the whole process of residential energy use. The electricity information acquisition system can realize accurate measurement, collection, storage, calculation, and analysis of power consumption data, market price, and power operation state [20]. Besides, synchronous management of the power system and household electricity consumption information based on 5G and other information technologies can be achieved through smart electricity meters, private power Internet networks, and intelligent interactive electricity service software to provide infrastructure and accurate and reliable information support for the implementation of demand response [21,22]. The construction of a community-level energy public service management platform can realize panoramic energy monitoring of residents, distributed generation grid connection, intelligent charging of electric vehicles, and joint optimization of the electricity-gas-heat system to realize interconnection and interaction for multiple types of energy use and loads in the community and thereby improve the flexible controllability of the terminal load [23,24].

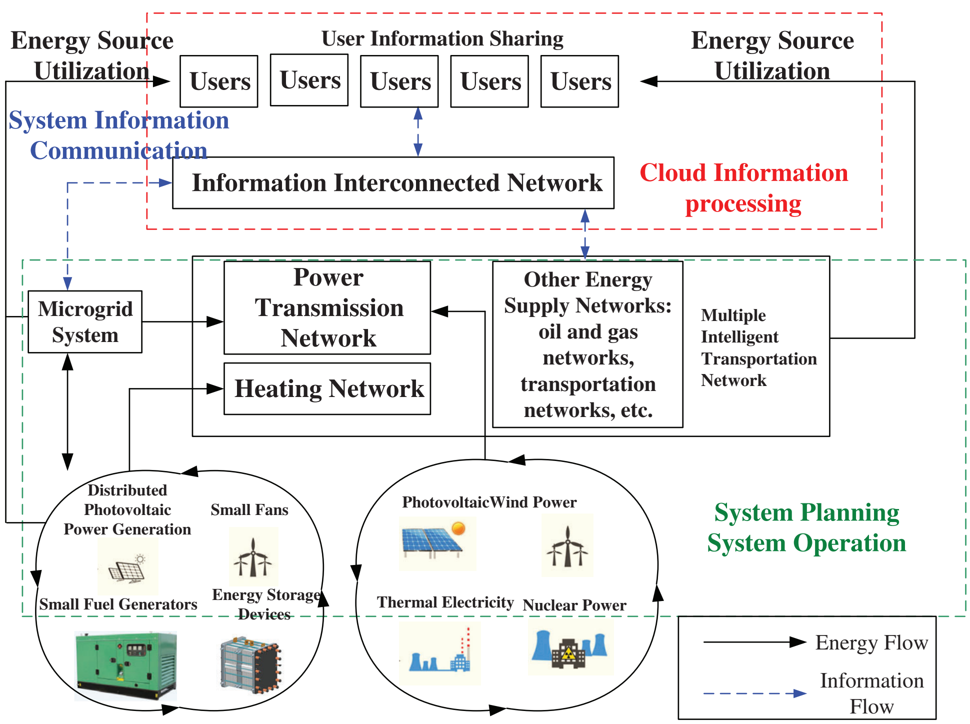


Figure 2: Basic architecture of the energy internet

A building-level demand response control system can be deployed. By installing intelligent sensors and intelligent terminals on centralized risk control, elevators, lighting, and other electrical equipment in buildings, panoramic monitoring of energy use can be realized [25]. When the system is further extended to cooling, heating and other energy uses, the system can realize joint optimal operation and echelon utilization of various energy sources and improve the comprehensive energy utilization efficiency of buildings.

In industrial zones with large users [26], on the one hand, load optimization of the park can be realized by improving the equipment operation process of productive loads and improving the intelligent level of nonproductive loads. On the other hand, through digital analysis of the energy-using strategy, precision of the strategy can be realized and the initiative of power users to participate in demand response can be improved. Based on the two-way information interaction, the demand response terminal equipment and control system are utilized to improve flexible load control and its self-balancing ability, to perform energy efficiency analysis for large users, and to improve the participation of park load control in power grid regulation.

3.3 System Architecture of Demand Response Based on Energy Internet

(1) Architecture of Demand Response Information Technology System.
The demand response system needs to have two modules of user management and equipment management, and it also needs to realize the five basic functions of effect evaluation [27], data monitoring [28], response execution [29], calling strategy [30], and regulation demand [31]. The basic structure of the demand response system is shown in Fig. 3. After the load integrators use the demand response system to adjust and collect data on buildings, industrial users, residential users, and emerging loads, the system can perform load monitoring and big data analysis on target objects.
The system can formulate control strategies and issue control requirements to load integrators. After the load integrator platform responds, the control strategy is issued in real time, and relevant data information is fed back to the master station of the demand response system. When each piece of equipment deployed on the user side receives instructions from the load integrator, it can sense and integrate physical devices and their status information on the spot through sensors, and use demand response terminals, energy gateways, and optimized control strategies to achieve equipment automation and response intelligentization [32].

(2) Architecture of Demand Response System Based on Energy Internet
Combining the design concept of the Cyber-Physical Systems (CPS) architecture and the Energy Internet technology architecture, a four-level demand response technology system including "terminal-edge-network-cloud" is constructed. "Terminal" refers to the intelligent sensing and control terminal of the user-side device. Through the deployment of various sensors and controllers, as well as the installation or modification of equipment such as solenoid valves, inverters, and host communication boards, full perception and control of the source equipment and building space units that generate data can be realized. "Edge" refers to the deployment of core algorithms for demand response based on big data, artificial intelligence, and edge computing. By deploying edge computing devices, such as demand response terminals and energy gateways, data, such as various electrical quantities (voltage, current) and thermal quantities (temperature, pressure, flow) at the terminal layer, are collected. By adopting containerization technology, the standardized information model and control strategy algorithm module is built in it. Through territorial edge computing, the model can perform flexible regulation of different application scenarios, such as industrial areas and buildings. "Network" refers to the integrated data network of demand response, which uses optical fiber, the private 5G network, the private Long-term Evolution (LTE) networks, the private 230 M network, and the public 5G network to build the Power Internet of Things. The network is responsible for providing safe and reliable communication channels for cloud-software collaboration, including both wired and wireless transmission methods. The cloud edge supports the Internet, private wireless network, power carrier, and other methods. "Cloud" refers to the cloud system of demand response businesses. The demand response system is deployed in the cloud to provide real-time load monitoring, load potential prediction, control strategy formulation, demand

response execution, and other micro-services and supports massive device access management, high-speed data processing, and air conditioning resources using visual management. The combination of big data mining technology, software-hardware, and cloud-software is used to collaboratively control to enhance flexible control capabilities. The overall structure of the system is shown in Fig. 4.

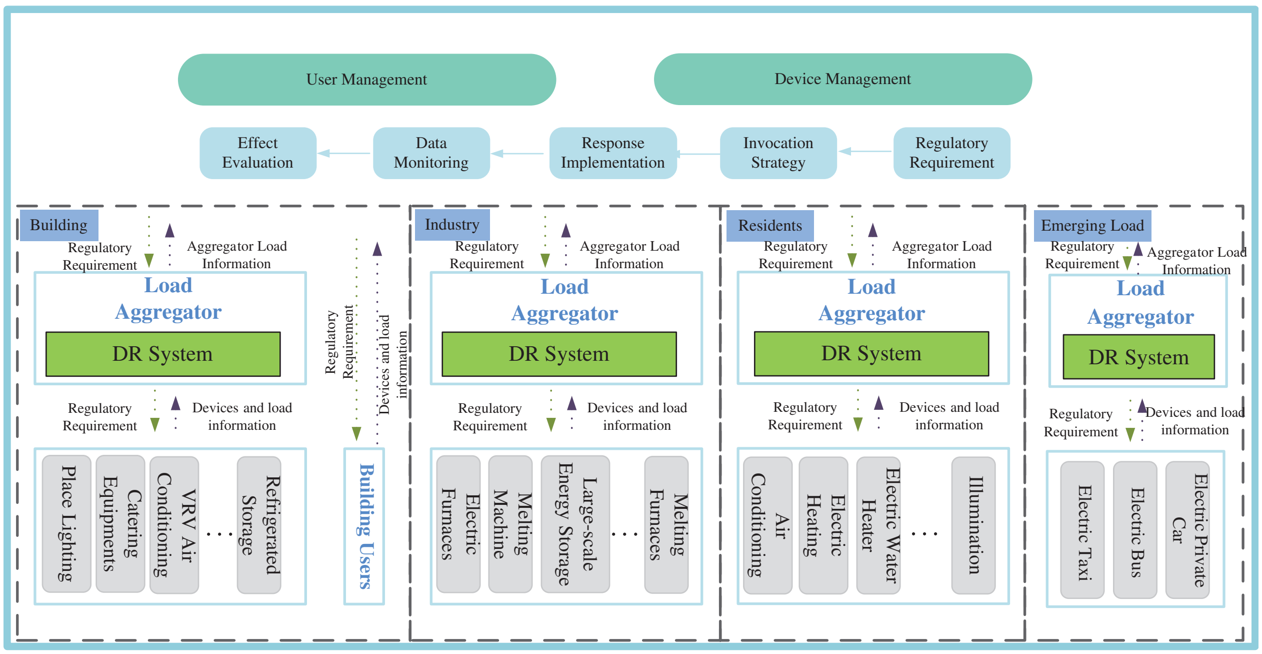


Figure 3: The architecture of demand response information technology system

The demand response system can unite social resources, such as load aggregators and energy-saving service providers; adopt the advanced information and communication technologies of the "network"; access diverse user-side equipment and control devices on the "terminal" side; apply edge computing technology to improve the intelligence and automation level of load response strategies; and coordinate with resources, such as the "cloud" side aggregator system, to realize the coordinated interaction of the demand response data flow, energy flow, and business flow. SOS-level CPS, such as the demand response system master station, demand response aggregator system, and demand response supervision system master station, can achieve cloud-end collaboration with system-level CPS and unit-level CPS through public communication networks. Among these, system-level CPS includes industrial user energy management systems, building user automatic control systems, etc.; unit-level CPS includes demand response terminals, smart sockets, etc.

3.4 Contents of the Information Technology System Construction

The system-side demand response system has a variety of functions, such as user resource management, user information access, grid control command reception, control strategy formulation and issuance, demand response process monitoring, performance evaluation, and cost settlement. At the same time, the system-side demand response system can dock with the smart home appliance cloud platform and the demand response aggregation system and supports various user-side demand response application scenarios through big data analysis and intelligent decision-making.

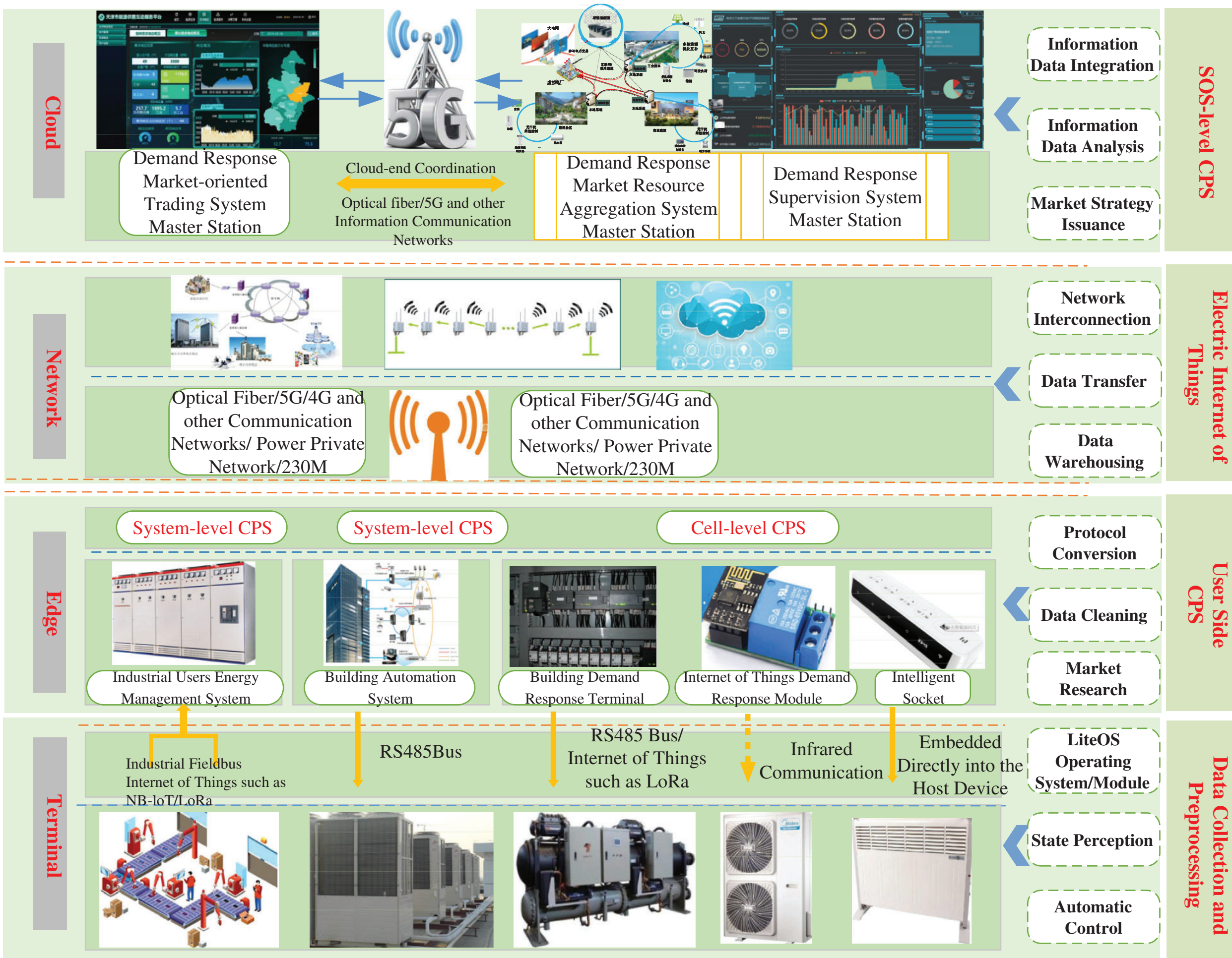


Figure 4: The architecture of demand response system based on energy internet

In the system-level CPS collaboration, the user side is integrated by the user-side energy management system such as the “edge” side industrial user operation management system and the building automation system. To further converge to the demand response aggregation system, it is impossible to directly integrate resources on the “cloud” side, and it is necessary to use the demand response integrated data network to realize cloud-side collaboration of the information. In the unit-level CPS system, collection and control are directly carried out by the intelligent collection terminal and on-site collection components, including various sensors and controllers that are directly connected to the demand response business system, and perform load sorting identification and integration calls on the “cloud” side.

Through the demand response aggregator system, load aggregators comprehensively manage the controllable resources of various power customers, connect to the enterprise-level control master station through the secure access area using flexible communication, and receive and respond to the latter’s load control needs in real time. As the “autonomous domain” unit of grid operation, the load aggregation platform has strong internal comprehensive coordination and flexible adjustment capabilities, which are embodied as follows: first, industrial customers, commercial customers, residential customers, and other various electricity customers are widely connected; second, the power exchanged with the grid is controlled within a predictable fixed range; finally, within a certain range, the platform can respond to the two-way load regulation demand of the grid in real time.

3.5 Analysis of the Development Trend for Demand Response

The construction of the Energy Internet will greatly promote the development of the demand response business. Through the construction of a demand response business ecosystem involving power grid enterprises, electricity selling companies, distributed generation enterprises, load aggregators, power users, and other parties, win-win cooperation can be achieved. Energy Internet technology is used to promote the supply and demand interaction regulation in regional areas and enhance the automation level of demand response. The coordinated control of wind power, photo-electricity, controllable load, and distributed generation can alleviate wind and light abandoning to realize the goal of energy transformation.

(1) The response mode is integrated.
The integrated demand response, further derived from the traditional power demand response, is closely related to the integrated energy network and integrated energy market in the Energy Internet, which is an extension of the power demand response theory in the context of the Energy Internet [33]. In brief, based on the integrated energy intelligent management system of Energy Internet, integrated demand response is a mechanism and means to guide and change users' comprehensive energy use behavior through multiple energy market price signals, including electricity, gas, and carbon trading.

(2) The implementers become diversified.
The implementation subjects of demand response have expanded from power grid companies to comprehensive energy service companies, energy-saving service companies, load aggregators and electricity selling companies, etc. Through the implementation of demand response, all kinds of subjects flexibly invoke the adjustable load resources of customers, calm the fluctuation of the generation power of distributed power on the user side, actively participate in the optimization operation of the power grid, postpone or avoid investments in the capacity increase of power distribution facilities, and improve the equipment utilization rate to improve the overall benefit of comprehensive energy service projects. The market participants also participate in transactions on the auxiliary power service market and the spot market by integrating the demand response resources.

(3) The operation mechanism becomes market-oriented.
As a new form of business, demand response will have more market-oriented characteristics with the deepening of electricity marketization reform. Based on existing policies, such as time-of-use price, demand response subsidy, and interruptible load price, more market-oriented measures, such as demand-side bidding and capacity auxiliary service, will be added [34].

(4) System decision-making becomes intelligent.
With the development of information and communication technology, such as cloud computing, big data, the Internet of Things, the mobile Internet, artificial intelligence, and blockchain, the demand response control system and application terminal are constantly upgraded. In the future, the adaptive optimization of user-side equipment based on artificial intelligence will be gradually developed. In a demand response information acquisition system, the demand response resource aggregation system and user side terminal application, the intelligent operation strategy library of the adaptive demand response is implanted to provide intelligent decision support for demand response aggregators and users, which is more efficient and economical to maximize the benefits of all parties [35].

(5) The execution mode becomes automatic.
The implementation mechanism of market-oriented demand response will become increasingly perfect in the future. With the development of edge computing and new sensing technology, intelligent response terminals and devices capable of automatically sensing fluctuations of the power grid operation state will be popularized over a wide range. The execution mode of demand response will gradually change from the power grid releasing response demand and

users participating in the response to the active perception and automatic execution of the demand response terminal. This mode not only realizes high automation and improves the implementation efficiency and effect but also reduces the dependence of demand response on user subjectivity and professional limitations.

4 Conclusions and Policy Recommendations

Facing the increasingly prominent contradiction between the supply and demand of power grid and the increasing installed capacity of new energy, this paper analyzed the current situation of demand response technology in China and typical countries. It was illustrated from the Energy Internet platform, demand response application scenarios, demand response system architecture based on Energy Internet, information technology system construction, and demand response development trend. Conclusions were as follows:

(1) The Energy Internet platform is applied to solve the problems of data acquisition and processing for demand response, “terminal-edge-network-cloud” cooperation, and so on.

(2) The proposed system architecture of the demand response platform supports user resource management, user information access, control instruction receiving, control policy issuing, and response process monitoring. Comprehensively considering the demand response time, participants, system operation, and other influencing factors and application scenario demands, the development trend of demand response under Energy Internet could be summarized from five dimensions by using Energy Internet technology, artificial intelligence analysis, and digital decision-making.

(3) The demand response system architecture and system construction scheme based on the Energy Internet platform proposed in this study is expected to provide a feasible technical choice for the expansion of Energy Internet application services towards the government and society.

However, this study only proposed a scheme conception of the demand response system platform based on the Energy Internet platform from the perspective of functional architecture. Further attention should be paid to completing the construction of the platform system from the technical level for data interface, data storage, security protection, and other issues in future studies.

With the gradual promotion of Energy Internet in China, support policies should be put forward from the following dimensions.

First, the seasonal time-of-use pricing mechanism should be improved. For different types of users, such as industrial users, business users, and residential users, their reductions of the power grid peak load, new energy generation consumptions, and other business needs are different. It is necessary to introduce differentiated and time-of-use policies for peak-valley electricity price to form sustainable economic incentives for demand response and to guide users to participate in demand response by themselves.

Second, users should be encouraged to build power management systems that meet demand response requirements. Local governments should issue subsidy policies to encourage large power users, such as industrial and commercial power users, to access the demand response aggregator system. Or, governments should build their power management system to support demand response work to improve the load monitoring capacity and provide appropriate subsidies according to user investment. At the same time, it is required that the load of new buildings must be connected to the demand response platform. Commercial and residential air conditioning equipment must have a demand response function. Users can receive subsidies when purchasing equipment with a demand response function.

Third, China should carry out demand response as a mandatory requirement for local governments at the national level. China should introduce policies that explicitly take power demand response as an important measure to achieve the power balance. All local governments should be required to set up a demand response resource pool within a time limit, and each province should break down their rational percent of adjustable capacity according to the specific situation of different regions. Power users should be required to cooperate in carrying out adjustable load surveys and be encouraged to connect adjustable loads to the demand response platform in the form of individual devices or enterprises.

Finally, demand response should be gradually incorporated into electricity market transactions. Each region should carry out differentiated construction according to the stage of electricity marketization, infrastructure construction conditions, and electricity supply and demand situation. Besides, the demand response trading varieties suitable for power grid peak load reduction and new energy generation consumption should be designed and be included in the spot power market or auxiliary service market. The long-term demand response mechanism of "whoever benefits shall bear" should be established to solve the problem of the funding source for demand response by market-based means. Governments at all levels should strive to promote this mechanism for the introduction of power demand response to participate in auxiliary services. Demand response resources should be packaged into a "virtual power plant" as soon as possible. Resources equivalent to power generation should be encouraged to participate in paid peak regulation, frequency modulation, standby, and other auxiliary services of the power grid to guide integrated energy service companies, demand response aggregators, and smart home (home appliances) manufacturers inside and outside the power grid to participate in market transactions.

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References

1. Wang, Y., Ding, J., Tian, S., Bu, F., Chen, J. (2019). An orderly power utilization mode based on intelligent multi–agent apanage management system. *Power System Technology, 43(5),* 1802–1814. DOI 10.13335/j.1000-3673.pst.2018.1315 (In Chinese).
2. Tan, Z., De, G., Li, M., Lin, H., Yang, S. et al. (2020). Combined electricity-heat-cooling-gas load forecasting model for integrated energy system based on multi-task learning and least square support vector machine. *Journal of Cleaner Production, 248,* 119252. DOI 10.1016/j.jclepro.2019.119252.
3. Zhang, J. (2021). Distributed network security framework of energy internet based on Internet of Things. *Sustainable Energy Technologies and Assessments, 44,* 101051. DOI 10.1016/j.seta.2021.101051.
4. Feng, C., Liao, X. (2020). An overview of "Energy+internet" in China. *Journal of Cleaner Production, 258,* 120630. DOI 10.1016/j.jclepro.2020.120630.
5. Tahir, M. F., Chen, H., Khan, A., Javed, M. S., Cheema, K. M. et al. (2020). Significance of demand response in light of current pilot projects in China and devising a problem solution for future advancements. *Technology in Society, 63,* 101374. DOI 10.1016/j.techsoc.2020.101374.
6. Liu, D., Gao, X., An, H. (2019). Supply and demand response trends of lithium resources driven by the demand of emerging renewable energy technologies in China. *Resources, Conservation and Recycling, 145,* 311–321. DOI 10.1016/j.resconrec.2019.02.043.
7. Albadi, M. H., El-Saadany, E. F. (2008). A summary of demand response in electricity markets. *Electric Power Systems Research, 78(11),* 1989–1996. DOI 10.1016/j.epsr.2008.04.002.

8. Larsen, E. M., Pinson, P., Leimgruber, F., Judex, F. (2017). Demand response evaluation and forecasting–Methods and results from the ecoGrid EU experiment. *Sustainable energy. Grids and Networks, 10,* 75–83. DOI 10.1016/j.segan.2017.03.001.
9. Alasseri, R., Rao, T. J., Sreekanth, K. J. (2020). Institution of incentive-based demand response programs and prospective policy assessments for a subsidized electricity market. *Renewable and Sustainable Energy Reviews, 117,* 109490. DOI 10.1016/j.rser.2019.109490.
10. Lu, X., Li, K., Xu, H., Wang, F., Zhou, Z. et al. (2020). Fundamentals and business model for resource aggregator of demand response in electricity markets. *Energy, 204,* 117885. DOI 10.1016/j.energy.2020.117885.
11. Torbaghan, S. S., Blaauwbroek, N., Kuiken, D., Gibescu, M., Hajighasemi, M. et al. (2018). A market-based framework for demand side flexibility scheduling and dispatching. *Sustainable energy. Grids and Networks, 14,* 47–61. DOI 10.1016/j.segan.2018.03.003.
12. Pinson, P., Madsen, H. (2014). Benefits and challenges of electrical demand response: A critical review. *Renewable and Sustainable Energy Reviews, 39,* 686–699. DOI 10.1016/j.rser.2014.07.098.
13. Wu, Y., Wu, Y., Guerrero, J. M., Vasquez, J. C. (2020). Digitalization and decentralization driving transactive energy Internet: Key technologies and infrastructures. *International Journal of Electrical Power & Energy Systems, 126,* 106593. DOI 10.1016/j.ijepes.2020.106593.
14. Zhao, M. (2017). The implementation status of demand response in the United States and its enlightenment to China. *Global Market Information Guide, 41,* 4–5. DOI 10.3969/j.issn.1005-4901.2017.41.002 (In Chinese).
15. Zhou, J. (2018). Enlightenment from the practice of power demand side management in Japan. *Energy Research and Utilization, 5,* 25–26+30. DOI 10.16404/j.cnki.issn1001-5523.2018.05.010 (In Chinese).
16. Li, G., Liu, J., Zhao, Y., Liu, J., Jiang, C. et al. (2016). The research of energy consumption optimization management technology for data center in the energy Internet environment. *Electrical Measurement & Instrumentation, 53(10),* 1–7+15. DOI 10.3969/j.issn.1001-1390.2016.10.001 (In Chinese).
17. Zeng, M., Yang, Y., Liu, D., Zeng, B., Ouyang, S. et al. (2016). Generation-grid-load-storage coordinative optimal operation mode of energy Internet and key technologies. *Power System Technology, 40(1),* 114–124. DOI 10.13335/j.1000-3673.pst.2016.01.016 (In Chinese).
18. Cai, Y., Feng, S., Du, H., Liu, M., Ding, X. (2019). Novel edge–ware adaptive data processing method for the ubiquitous electric power Internet of Things. *High Voltage Engineering, 45(6),* 1715–1722. DOI 10.13336/j.1003-6520.hve.20190604005 (In Chinese).
19. Jiang, S., Yang, L., Liu, Q., Yang, L. (2020). Research on comprehensive energy optimization of energy interconnected parks considering flexible load. *Electrical Measurement & Instrumentation, 57(16),* 83–88. DOI 10.19753/j.issn.1001-1390.2020.16.015 (In Chinese).
20. Arcos–Vargas, A., Lugo, D., Núñez, F. (2018). Residential peak electricity management. a storage and control systems application taking advantages of smart meters. *International Journal of Electrical Power & Energy Systems, 102,* 110–121. DOI 10.1016/j.ijepes.2018.04.016.
21. Salahuddin, M., Alam, K. (2015). Internet usage, electricity consumption and economic growth in Australia: A time series evidence. *Telematics and Informatics, 32(4),* 862–878. DOI 10.1016/j.tele.2015.04.011.
22. Dijkman, R. M., Sprenkels, B., Peeters, T., Janssen, A. (2015). Business models for the Internet of Things. *International Journal of Information Management, 35(6),* 672–678. DOI 10.1016/j.ijinfomgt.2015.07.008.
23. Jin, C., Xu, J., Liao, S. (2019). Coordination strategy of residential demand response based on smart meter. *Electrical Measurement & Instrumentation, 56(13),* 136–141,*147*. DOI 10.19753/j.issn.1001-1390.2019.013.023 (In Chinese).
24. Dranka, G. G., Ferreira, P. (2020). Load flexibility potential across residential, commercial and industrial sectors in Brazil. *Energy, 201,* 117483. DOI 10.1016/j.energy.2020.117483.
25. Zeng, M., Yang, Y., Li, Y., Zeng, B., Cheng, J. et al. (2016). The preliminary research for key operation mode and technologies of electrical power system with renewable energy sources under energy internet. *Proceedings of the CSEE, 36(3),* 681–691. DOI 10.13334/j.0258-8013.pcsee.2016.03.011.

26. Zhong, Y., Wang, L., Zheng, Y., Yin, J., Guo, Z. et al. (2020). Comprehensive evaluation index system for integrated energy system in industrial park. *Power Demand Side Management, 22(3),* 51–56. DOI 10.3969/j.issn.1009-1831.2020.03.011 (In Chinese).
27. Nolan, S., O'Malley, M. (2015). Challenges and barriers to demand response deployment and evaluation. *Applied Energy, 152,* 1–10. DOI 10.1016/j.apenergy.2015.04.083.
28. Wang, Z., Zhao, W., Deng, N., Zhang, B., Wang, B. (2021). Mixed data-driven decision-making in demand response management: An empirical evidence from dynamic time–warping based nonparametric-matching DID. *Omega, 100,* 102233. DOI 10.1016/j.omega.2020.102233.
29. Li, B., Zhou, Q., Chen, S., Cui, G., Qi, B. et al. (2017). Data analysis model for demand response system and its application. *Electric Power Construction, 38(9),* 88–94. DOI 10.3969/j.issn.1000-7229.2017.09.013 (In Chinese).
30. Shariatzadeh, F., Mandal, P., Srivastava, A. K. (2015). Demand response for sustainable energy systems: A review, application and implementation strategy. *Renewable and Sustainable Energy Reviews, 45,* 343–350. DOI 10.1016/j.rser.2015.01.062.
31. Shen, Y., Yue, Y., Yan, H., Chen, X., Li, D. et al. (2017). Research on aggregation and optimization strategies of demand response resources for regional power grid. *Power System Technology, 41(10),* 3341–3348. DOI 10.13335/j.1000-3673.pst.2017.1025 (In Chinese).
32. Zeng, M., Wu, G., Li, R., Wang, H. J., Sun, C. J. (2016). Key problems and prospects of integrated demand response in energy Internet. *Power System Technology, 40(11),* 3391–3398. DOI 10.13335/j.1000-3673.pst.2016.11.017 (In Chinese).
33. Wang, J., Zhong, H., Ma, Z., Xia, Q., Kang, C. (2017). Review and prospect of integrated demand response in the multi-energy system. *Applied Energy, 202,* 772–782. DOI 10.1016/j.apenergy.2017.05.150.
34. Kong, Y., Feng, C., Yang, J. (2020). How does China manage its energy market? A perspective of policy evolution. *Energy Policy, 147,* 111898. DOI 10.1016/j.enpol.2020.111898.
35. Zhang, Q., Ma, Y., Wang, Y. (2019). Research on micro–grid interconnection based on demand side response. *Electrical Measurement & Instrumentation, 56(10),* 34–39. DOI 10.19753/j.issn.1001-1390.2019.010.006 (In Chinese).