Current Status And Prospects Of Research On New Urban User-side Energy Interconnection System Planning

Peng YE1, Zheng bin ZHANG2*, Huan WANG3, Duo jiao GUAN4, Ming li ZHANG5, Na ZHANG6
1,2,3,4Shenyang Institute Of engineering, Shenyang, China
5,6Economic and Technological Research Institute of State Grid Liaoning Electric Power Co., Ltd, Shenyang, China
* Corresponding author: zhangzhengbin1998@163.com

Abstract—Constructing a new-type urban user-level energy interconnection system, comprehensively considering user-side energy characteristics to optimize the "source-network-load" structure, which is conducive to awakening the potential of users to delay load peak shaving, and realizing the local consumption of renewable energy, which is a solution for small towns. An important means to balance supply and demand. Based on the initiative of users to use energy, this paper divides the user energy interconnection system into residential users, industrial and commercial users, and electric vehicle users. First, it outlines the connotation of the energy Internet and the architecture of the user-side energy interconnection system. Secondly, it summarizes the planning model of user energy interconnection system. Subsequently, according to the "source-network-load" structure, the configuration of the user-side energy interconnection system is analyzed from the perspective of planning. Finally, this article briefly prospects and discusses the factors that need to be considered in the future user energy interconnection system planning.

1. INTRODUCTION
With the continuous improvement of the level of social productivity in my country, the development of science and technology, and the optimization of the industrial structure, the level of urbanization is getting higher and higher. The prerequisite for urbanization and urban development is urban energy planning. The town-level energy interconnection system can be divided into three levels: hub, region, and user according to the size of the interconnected area and the connection method[1]. The user energy system is the main end consumer of urban energy, and reasonable planning is of great significance for improving the utilization rate of renewable energy and promoting the local consumption of renewable energy. At present, the urban user energy system is mainly the building cooling, heating and power cogeneration system, with the cooling, heating and power cogeneration system as the core. Space heating, space refrigeration, hot water, etc., realize the cascade utilization of energy by centrally providing users with electric energy, cold energy and heat energy[2]. However, the energy gradient utilization method cannot meet the "diversified needs" of urban energy users. At the same time, in the context of the Energy Internet, users no longer exist only as energy consumption links. The development of new energy power generation technology has led to the participation of users in power generation methods such as photovoltaic user groups. Users can also act as energy producers to further influence the urban energy interconnection system. The planning brings challenges.
Therefore, this article uses the urban energy Internet as the background to divide urban users into residential users, industrial and commercial users, and electric vehicle users. Firstly, it sorts out the connotation of the energy Internet and proposes the basic architecture of the new urban user-side energy interconnection system; secondly, it summarizes the modeling methods of the user-side energy interconnection system; thirdly, according to the "source-network-load" structure, the user-side energy interconnection system configuration is analyzed; finally, the future direction of planning the user-side energy interconnection system that needs further research is prospected.

2. CONNOTATION OF ENERGY INTERNET AND SYSTEM ARCHITECTURE

2.1. Connotation Of Energy Internet
The essence of the energy Internet is the large power grid as the “backbone network”. Each distributed energy network forms an energy local area network (LAN), and multiple LANs are connected through electricity, gas, and heat networks to form an energy wide area network (WAN). The Energy Internet is based on the power grid and integrates multiple renewable energy generation technologies, distributed energy technologies, and information and communication technologies. It combines energy flow and information flow to establish energy in which multiple entities participate in supply, multiple entities participate in regulation, and multiple entities participate in consumption. Shared network.

2.2. New Urban User-side Energy Internet Architecture
The new urban users are mainly residential users, industrial and commercial users, and electric vehicle users. Among them, industrial and commercial users are composed of multi-energy conversion equipment and energy storage equipment, which are the core of the energy coupling of the user-side energy system; residential users are composed of energy consumption equipment and the main energy consumption terminal in cities and towns. In addition, with the increasing development of new energy power generation technology, a large number of electric vehicle users have emerged, which is characterized by the random distribution of load positions in the transportation network. The architecture of the user-side energy interconnection system is shown in Figure 1.

![Basic architecture diagram of the new urban user-side energy interconnection system](image)

3. USER-SIDE ENERGY INTERCONNECTION SYSTEM MODELING

3.1. Energy Conversion Device
Industrial user energy interconnection systems are usually equipped with multiple energy conversion devices. Among them, combined heating and power (CHP) and power to gas (P2G) are the core of industrial users’ energy conversion, which promotes a variety of Energy coupling.

1) Combined heat and power plant
The proposal of CHP deepens the coupling between the power grid and the heating network. Its typical mathematical model is[3]:

\[
P_{\text{H,MT}}(t) = \frac{P_{\text{MT}}(t)(1-\eta_{\text{MT}} - \eta_{\text{L}})}{\eta_{\text{MT}}} \tag{1}
\]
In the formula, $P_{H,MT}(t)$, $P_{MT}(t)$, $\eta_M$, $\eta_t$, $C_o$, respectively, the output waste heat power, output electric power, power generation efficiency and heat loss rate of the micro-gas turbine at time $t$; $H_{MT}(t)$, $\eta_A$, $\eta_C$, respectively, the heating power, heating coefficient and flue gas recovery rate at time $t$; $H_{tmt}(t)$ Heating capacity at time $t$.

2) Electric to gas device

The P2G concept first proposed by Germany is mainly divided into two steps: electricity-to-hydrogen and electricity-to-natural gas. The proposal of P2G promotes the coupling of power grid and gas grid, and its basic principle is shown in Figure 2.

![Figure 2. P2G device flow chart](image)

3.2. Household Appliances Model

In the consumer segment of the urban energy Internet, the traditional household power supply method can no longer meet the development needs of the energy Internet. At present, the main solution to such problems is to divide the household electricity load into delayable load and non-delayable load, and build a family microgrid to flexibly dispatch energy to meet the electricity demand of household users[4].

1) Electrical load can be delayed

The load can be adjusted by delaying the load of electrical appliances, such as air conditioners, water heaters, etc. It has the characteristics of flexible scheduling, and its mathematical model is:

$$P_h = a_s(h) = d_a$$

$$S_a(h) = \begin{cases} 0, & \text{if } h \in [1,H] \text{ and } a \notin [\alpha_a, \beta_a] \\ 0 \text{ or } 1, & \text{if } h \in [\alpha_a, \beta_a] \end{cases}$$

$$P_{def}(h) = \sum_{a=1}^{A} S_a(h) P_a, \forall h \in [1,2,\cdots,H]$$

In the formula, $[\alpha_a, \beta_a]$ Indicates the allowable working range of the electrical load that can be delayed; $d_a$ Indicates the period of time during which the electrical load can be delayed; 0 and 1 respectively indicate that the electrical load can be delayed in the standby state and the working state; H indicates that the time of day is divided into several equal time periods, period $h \in [1,2,\cdots,H]$; A indicates the number of electrical loads that a resident user can delay, $a \in [1,2,\cdots,A]$; $P_{def}(h)$ Indicates the total electrical power used by the electrical load that can be delayed.

2) Do not delay electrical load

Non-delayable electrical load, that is, non-adjustable load, refers to electrical equipment that cannot participate in optimal dispatch, such as induction cookers, lights, etc. If controlled to participate in
dispatch optimization, it will cause extreme discomfort to residents. Therefore, the electrical load that cannot be delayed can be considered as a constant power.

4. Research on the "Source-Network-Load" Planning of User Energy Interconnection System

4.1. Multi-source Collaborative Planning Based on User-side Energy Routers

At present, the construction of an energy Internet with energy routers as the core coordinated control is considered to be an important means to achieve a balance between supply and demand after a high proportion of renewable energy is connected to the grid\(^5\). The energy transmission model of the energy router is shown in Figure 3.

![Energy transmission model of energy router](image)

Figure 3. Energy transmission model of energy router

In view of the functions and characteristics of user-side energy routers, \(^6\) proposes that energy routers should meet multiple energy access ports, have a plug-and-play interface, and include multiple communication technologies to meet the needs of two-way intelligent interconnection of energy. For the user-side energy LAN planning, \(^7\) proposes to use the energy router as the core control device of the energy LAN, divide the user-side energy Internet into multiple energy LANs, and establish a two-layer planning model for the user-side energy interconnection system. The routers coordinate and complement each other to realize the complementarity of multiple energy LANs. On this basis, \(^8\) proposed the concept of virtual routers, that is, through information and communication technology, multiple distributed energy routers are centralized, coordinated and optimized, and a virtual router multi-energy coupling correlation model is established to realize the connection between user-side energy LAN and energy WAN. Energy interaction.

4.2. Cooperative Planning Based on Multiple “networks” Of User-side Energy Network-Transportation Network Coupling

At present, the research on urban user-side energy network planning is mainly divided into: grid-gas network coordinated planning\(^9\), grid-heating network coordinated planning\(^10\), grid-gas network-heating network coordinated planning\(^11\), and energy network. The resulting traffic electrification is also an important part of energy Internet planning.

The current research on user-side energy grid-transportation collaborative planning is mainly aimed at rationally planning new energy charging stations to promote grid-transportation coupling. Reference \(^12\) proposes an integrated photovoltaic storage and charging electric vehicle charging station that comprehensively considers the intermittency of photovoltaic power generation and the economics of charging and discharging. The capacity and number of charging piles in the station are decision variables to establish a multi-objective function planning model. The calculation example verifies that the integrated optical storage and charging station has better economic efficiency, and at the same time promotes the coupling of the energy network and the transportation network.

With the continuous development of user energy interconnection systems, electric vehicle users, as small and irregular distributed energy storage devices in the energy interconnection system, that is, distributed power sources, how to establish a distributed power source model, simulate their driving and charging behavior, and promote electrical -The transportation network is highly coupled, which is worthy of further in-depth study.
4.3. Multi-“load” Collaborative Planning Based On User-side Comprehensive Demand Response

The traditional demand response (DR) response model is not enough to respond to the response demand of the energy interconnection system. The integrated demand response (IDR) has effectively solved this problem. IDR is the foundation of DR In the above, considering the high proportion of new energy access and the complementary characteristics of each energy, that is, the user-side demand is no longer unilaterally defined as electricity demand, and the electricity users are expanded to electricity-heat-gas and other multi-energy users, which effectively promotes renewable energy Of consumption.

In the residential, industrial and commercial user-side energy interconnection system planning that takes into account IDR, for industrial users, [13] proposes to minimize cost as the goal, and establishes a planning model that takes IDR into account. Finally, heat-electricity coupled industrial users As an example, it is verified that the planning model that takes IDR into account can better utilize the complementary characteristics of industrial parks. For residential users, [14] considers the electricity consumption habits of residential users and establishes an IDR optimization model for urban residents, which verifies that considering the IDR of residential users can improve the response potential.

Different from traditional industrial, commercial and residential users, electric vehicle users are affected by traffic congestion, charging price, charging waiting time, remaining battery life, etc., and the location of load power is not fixed and random, as shown in Figure 4. How to make reasonable use of the response potential of electric vehicle users while ensuring the satisfaction of electric vehicle users is an important topic for user-side energy Internet planning. For the energy interconnection system planning that considers the IDR of electric vehicle users, the charging behavior of users must first be considered.

Figure 4. Factors to be considered when planning electric vehicle users

As mentioned above, considering the user-side IDR can improve the grid's ability to absorb clean energy to a certain extent and reduce the pressure on the grid. However, most of the current research on user-side IDR studies its impact on system reliability from a macro perspective, taking the user-side as a whole. However, the user's subjective willingness, user comfort and other behaviors are also issues that cannot be ignored.

5. PROSPECTS FOR IN-DEPTH RESEARCH

5.1. Coordinated Planning Of DC Conversion Of Electrical Equipment Considering User Load

At present, most of the research related to user-side energy Internet planning focuses on the coupling of multiple energy sources. However, with the continuous development of power electronics technology, electrical equipment has gradually moved towards the "direct current" road. Joint planning of a multi-energy coupling interconnection system and a low-voltage DC system in the user-side energy interconnection system to reduce unnecessary AC/DC conversion links is of great significance to reducing system losses and improving system efficiency.
5.2. Considering Users' participation In The Coordinated Planning Of Electricity Spot Market Transactions

With the increasing access to a high proportion of new energy sources, user needs are gradually showing diversified characteristics. The traditional mid- and long-term power market transaction model can no longer take into account the volatility and intermittent characteristics of new energy. Electricity spot market transactions adopt the trading mechanism of day-to-day real-time energy trading, which is conducive to promoting new energy consumption, realizing short-term real-time energy trading, and having better economic benefits. How to realize a transaction mode in which residential users participate in bidding with households as a unit and industrial and commercial users with parks as a unit, and build an energy interconnection system that considers users' participation in power spot market transactions, will help to further optimize the configuration of the energy interconnection system for urban users.

6. SUMMARIZE

In the context of the continuous increase in the proportion of urbanization and the continuous development of energy interconnection technology, research on user-side energy interconnection systems has long-term significance for the realization of the global energy interconnection. This article starts from the current research status of the urban user energy interconnection system, and summarizes the system architecture, system modeling, system planning, and future issues to be considered. It is of great significance to the development of the new urban energy Internet.

REFERENCES

[1] Wang D, Meng Z J, Jia H J, Li J R, Yu J C, Zhang Z Y. Research and prospects on key technologies of energy interconnection system planning for new towns[J]. Automation of Electric Power Systems, 2019, 43(14): 16-28.

[2] Zhang X, Zhang Y M, Ji X Q, Han X S, Yang M, Xu B. Considering the coordinated optimal dispatch of transmission and distribution of the electricity-gas-heat integrated energy system[J/OL]. Power grid technology: 1-14[ 2021-11-24].https://doi.org/10.13335/j.1000-3673.pst.2021.2065.

[3] Liu H, Zhu T, Zhang T. Evaluation and analysis of CCHP-ORC system for different types of buildings in Shanghai area[J]. Proceedings of the Chinese Society for Electrical Engineering, 2016, 36(12): 3198-3206. DOI: 10.13334/j.0258-8013.pcsee.152217.

[4] Li S L, Yang J J. Real-time optimization strategy of household renewable energy based on dual battery packs [J]. Renewable Energy, 2019, 37(07): 1007-1014.

[5] Wang J Y, Li Y, Lu Z M, Sheng W X, Cao J W. Research on local energy internet based on energy switches and routers[J]. Proceedings of the Chinese Society of Electrical Engineering, 2016, 36(13): 3433-3439+3362.

[6] Liu X Z, Zheng Z D, Li Y D. Multi-port energy router using power electronic transformer[J]. Electric Drive, 2016, 46(04): 80-83.

[7] Wu C, Tang W, Bai M K, Zhang L, Cong P W. User-side energy internet planning based on two-tier planning[J]. Journal of Electrotechnical Technology, 2017, 32(21): 122-131.

[8] Zhang L Q, Chen A K, Gu J, Xie D, Gu C H. Regional energy wide area network collaborative planning based on multi-energy network routing algorithm[J]. Proceedings of the Chinese Society of Electrical Engineering, 2020, 40(23): 7499-7511.

[9] Yang Z J, Gao C W, Zhao M. A review of research on power-natural gas network coupling system[J]. Automation of Electric Power Systems, 2018, 42(16): 21-31+56.

[10] Yu D L, Cao J, Tu C W, Wang Z L, Lv C, Wang H F. Optimal energy flow analysis of electric-thermal multi-energy system considering linearized network constraints[J]. Proceedings of the Chinese Society of Electrical Engineering, 2019, 39 (07):1933-1944.

[11] Liu X R, Li Y, Sun Q Y, Pan Y L. Dynamic state estimation of electricity-gas-heat coupling network based on multiple time scales[J]. Power System Technology, 2021, 45(02): 479-490.
[12] Zhang Y, Han W, Song C, Yang S Y. Joint optimization of facility planning and operation of integrated solar storage and charging power stations with electric vehicles [J/OL]. Energy Storage Science and Technology: 1-12 [2021-11-18].https://doi.org/10.19799/j.cnki.2095-4239.2021.0481.

[13] Gao Q, Liu C, Jin D J, Dong Y B, Chen C M, Lin Z Z. Optimal configuration of the park's integrated energy system considering comprehensive demand response[J]. High Voltage Electrical Apparatus, 2021, 57(08): 159-168.

[14] Luo J M, Wen Z C, Dong W J, Li Z W, Liu Z X, Wu H T. Quantitative model of comprehensive energy demand response potential based on residential user portraits[J]. Renewable Energy, 2020, 38(10): 1407-1414.