A Survey on Hybrid Energy Systems Market

WU Hengtian1*, DAI Hongcai1, KONG Weizheng1

1 State Grid Energy Research Institute Co. Ltd., Beijing,102209, China

*Corresponding author’s e-mail: wuhengtian@sgeri.sgcc.com.cn

Abstract. The fast-growing energy needs over the last few years across the world have intensified challenges: how to reduce the generation and operation costs in power systems and, in parallel, to minimize the hydrocarbon emissions. The hybrid energy system (HES) provides overarching opportunities for solutions to aforementioned challenges. The paper starts with the classification of the energy supply and consumer in the market. Next, the HES operation and services are introduced. In the final, the typical market competition relationships of HES energy trading are proposed and analysed.

1. Introduction

1.1. Motivation

Over the last decade, the power grid operations have become more stressed due to growing customer demand and less secure with the integration of intermittent renewable resources. The energy conservation and emission reduction have been focused and concerned all over the world. Reducing fossil fuels usage and increasing clean energy consuming help directly to minimize the hydrocarbon emission. Aspects including improving the comprehensive utilization efficiency of various types of energy, realizing the cascade utilization of energy and reducing the emission of pollutants have become key issues for building a clean, low-carbon, safe and efficient modern energy system in China.

While the physical coupling of the energy system is becoming more and more close, the non-synchronization of the energy market will also lead to the distortion of market signals[1-2]. The on-grid electricity price of natural gas power plants lacks linkage with natural gas price, leading to the operation difficulties of natural gas power plants. In addition, the relatively low supply priority formulated by the administration leads to the gas supply of natural gas power plants cannot be guaranteed, and the peaking potential of natural gas power plants is difficult to play. These cases reflect the lack of price transmission mechanism in China’s different energy markets, the distortion of price signals resulting in insufficient investment, energy supply and demand imbalance and other problems.

1.2. Benefits

As an important component of new generation energy system, with various forms of power energy conversion and storage devices, the hybrid energy system (HES) integrates a variety of energy sources including power supply, heating, gas and electrified transportation system[3-4]. In the link of source-network–loads, coupling of different kinds of energy can be achieved by HES. Between the variety of heterogeneous energy subsystems, technologies advantages of HES evolves completely including coordinated planning, optimal operation, cooperative management, interaction response and complementary to each other aid.
We define hybrid energy systems (HES) as: multiple energy generation, storage, and/or conversion technologies that are integrated—through an overarching control framework or physically—to achieve cost savings and enhanced capabilities, value, efficiency, or environmental performance compared to the independent alternatives.

2. Market Players of Supply-side

2.1. Gas Suppliers
Natural gas is highly fungible and can be replaced by gas, liquefied petroleum gas, fuel oil and coal[5-6]. It is a typical demand-driven industry. When the end price of natural gas exceeds the price of alternative sources that produce the same calorific value, users opt for other fuels. The import of natural gas exploration and development has the characteristics of high cost, high investment and long time pre-investment. The supply capacity of natural gas suppliers is inelastic in the short term. On the demand side, there were big swings in the weather and the price of alternatives. The spot market of natural gas presents relatively violent volatility, and the risk is high.

2.2. Combined Heat and Power (CHP) Units
CHP unit is the core of multi-energy coupling in HES. CHP units make money by buying natural gas and selling the electricity and heat they produce. Due to the restriction of heat transmission distance, CHP unit has the characteristics of regional monopoly. The thermal energy commodities of CHP are mainly in competition with the boiler, heat storage and electric heat pump at the distribution network level. CHP’s power commodities mainly compete with the power wholesale market at the transmission grid level and the renewable energy generation and energy storage at the distribution network level, as Table 1 shows. Due to the characteristics of rapid start and stop, CHP units can also gain benefits by participating in the electricity auxiliary service market and the demand response initiated by comprehensive energy service providers under the condition of certain thermoelectric decoupling ability.

Table 1. Market behavior characteristics of CHP units

| Gas Price | Power Wholesale Price | Behavior characteristics of CHP units in typical scenes |
|-----------|------------------------|--------------------------------------------------------|
| High      | Low                    | ① The heating cost of gas-fired boilers and CHP units is higher than that of electric heat pumps, and the power supply cost of CHP is also higher than that of electricity purchase in the wholesale electricity market. At this time, CHP and gas-fired boilers have no market competitiveness. ② The heating market is dominated by thermal storage or electric heat pumps, while the power supply market is dominated by wholesale power, electric storage and renewable energy generation. ③ CHP, as the only heat source in the region, sets the electricity by heat. The deficient power is purchased from the wholesale market or output by electric energy storage, which raises the retail heat price. |
| Low       | High                   | ① Reduce the retail heat price and motivate users to increase the thermoelectric demand ratio. ② Using heat storage to achieve thermoelectric decoupling. |

2.3. Renewable Energy Power Stations
Renewable energy power stations mainly include photovoltaic power stations and wind power stations, which are characterized by high long-term marginal cost and low short-term marginal cost.

Renewable energy power stations have a low energy density. Considering the 24-hour sunshine for 10,000 households, 250,000 square meters of photovoltaic modules are needed. The cost disadvantage of renewable energy power station in economically developed load centre is obvious because of the rent, tax and equipment cost brought by the large area of land demand. Because there is no need to buy fuel, renewable power stations have a near-zero short-term marginal cost. Areas with low land costs and abundant solar and wind resources are ideal sites for renewable energy power stations. At
the same time, the distance from the load centre can bring the problem of line congestion. Purchasing transmission rights has become an important strategy for renewable energy power stations.

In the case of wind and solar output, renewable power stations have a strategy of bidding as low as possible or even zero prices to ensure that they can be sold in the centralized market of the joint market. This means that conventional power plants are at risk of being forced to shut down frequently during periods when renewable power plants are intermittently overpowered. Frequent start-up and shutdown costs can drive conventional power plants into the red. However, due to the intermittent and uncertain characteristics of renewable energy, a certain proportion of traditional energy power plants is the basis for the safe and stable operation of the system.

Due to the uncertainty of renewable energy output and difficult to predict in the long term, renewable energy power stations mainly participate in the spot market. So they can give full play to the low marginal cost to obtain the advantage of high risk and high yield.

2.4. Transmission network Investor

Electric power, natural gas and hot water transmission network are natural monopolistic links, which are all monopolized by enterprises with franchise rights under government supervision to avoid resource waste caused by repeated investment. The main body of investment in pipeline or network is generally the operator of energy system. The main investment body of hot water pipe network even plays the role of producer. Operators invest in the construction of pipe or network and shoulder the responsibility of system scheduling and operation and organizing market transactions.

Generally, the total permissible income of the pipeline network operator is calculated according to the cost plus method, and the transmission and distribution fees are charged to the end users according to a certain apportionment mechanism based on a one-part system or a two-part system price divided into capacity fee and usage fee. Marking refers to multiplying the permitted return rate by the effective assets, and the verification of effective assets is the core of the pipeline network operators’ earning and gaming with the regulatory authorities[7-8]. If the rate of return is allowed to be fixed, the pipeline network operators have the impulse to enlarge the effective assets and count some assets of non-transmission and distribution business into the effective assets to obtain more income, thus resulting in low production efficiency. The permitted rate of return can fluctuate according to the actual utilization rate of assets. For the pipe network with excess production capacity, the permitted rate of return should be appropriately reduced. The permissible rate of return can be increased appropriately for the pipe network with serious blockage and aging equipment.

The power system is characterized by real-time supply and demand balance and difficulty in mass storage. Electric power commodity trades and conveying rights are bundled. When the power transaction is cleared, the power users who get cleared automatically get the right to use the transmission line. In addition to transmission and distribution electricity fee, there is also blocking cost in the nodal electricity price. Together, they reflect the cost and scarcity of electricity transmission.

Unlike electricity, natural gas can be stored in large quantities and has more dynamic transmission characteristics. Natural gas systems operate more flexibly than electric systems. Commodity trading and transmission services in the gas market are decoupled. The completion of the deal between the buyer and the seller does not mean that the gas will be delivered smoothly. Natural gas pipeline company divides the gas delivery service into fixed gas supply service and interruptible gas supply service according to different service grades. For fixed gas supply service, the pipeline company provides continuous gas supply service according to the agreed time and volume of gas supply by the user, and charges the user in a two-part system. The capacity charge is used to recover the demand cost of pipeline transportation and has nothing to do with the gas consumption of the consumer. User fees are charged according to actual usage, reflecting variable costs. Interruptible customers may be reduced or cut off during peak periods. Therefore, fixed service users should bear higher reservation capacity charges than interruptible users.
3. Demand Side Market Players

3.1. Industrial Users
Industrial users generally consume more energy and demand more energy, and the energy cost accounts for a higher proportion of the overall production cost of industrial users. Therefore, industrial users have a strong desire to buy cheaper energy in the market to reduce the production cost of enterprises. Due to the large amount of energy used by industrial users, they generally participate in the wholesale energy market transactions and sign large energy transaction contracts in advance to ensure the long-term stable supply of energy for industrial users and reduce the risks brought by price fluctuations in the spot energy market to enterprises. At the same time, because of the sharp fluctuation of energy price in the spot market, industrial users will conduct peak shifting production according to the real-time energy price, thus reducing the energy purchase cost of enterprises. Due to the continuous production of industrial users, they have high requirements on the reliability of energy supply. Therefore, their load response to the energy market price is limited by the continuous production of industrial users, and has a certain proportion of base load which is not affected by the price.

3.2. Business Users
The load of commercial users is mostly service type load, which can be divided into unregulated load and adjustable load according to the nature of specific service. In terms of energy types, they mainly include power load, domestic thermal load and natural gas load[9]. There are many types of power loads, including not only unadjustable loads such as lighting equipment, office equipment and elevator equipment, but also adjustable loads such as air conditioning, ventilator and water heater. Among them, adjustable loads have a higher response degree to real-time electricity price. The thermal load of commercial users is mainly domestic hot water and heating load, which has a large inertia and strong adjustment ability. Besides, the thermal load power of commercial users is high, and they have a strong adjustment willingness in view of the real-time heat price. The natural gas load of commercial users is mainly for cooking equipment, heating equipment and water heater, among which the heating equipment and water heater have strong adjustability. To sum up, it can be seen that for commercial users, their main load is to provide commercial services, and their energy consumption is mainly to provide satisfactory services, with price as the second consideration. Since the service effect of temperature control load is less different after adjustment, its regulation potential is greater. Commercial users are also willing to adjust the load according to the market energy price so as to obtain profits.

3.3. Residents Users
Residential users mainly use domestic energy. As for individual residential users, their energy consumption volume is small, so they cannot participate in the energy wholesale market, but can only participate in the retail market[10]. As a result, its energy-using price in the market environment affected by its choice of comprehensive energy service providers. Among them, the power of real-time price, natural gas and heat load life price fluctuation is relatively slow, and the adjustment cycle is from 1 day to 1 months. Therefore, time scales of natural gas and heat load response to the market price is larger. At the same time, due to the different income levels of different residents, the extent of their response to the market price is also different. The lower the income is, the higher the proportion of energy consumption in their living expenses is, and with stronger willingness to participate in market regulation. As the construction of smart grids and Internet of things, the residents of the user's home appliances develop gradually to intelligence. Its internal built-in chips, according to the real-time release of the energy prices on Internet, automatically adjust power, so as to realize the effect of lower energy costs, which shows that with the popularity of smart appliances, residents will further enhance the user's response.
3.4. Electric Vehicles
With the popularity of electric vehicles, the overall power of electric vehicles is relatively high, and the impact of charge and discharge on the power grid should be considered[11]. The charging and discharging time distribution of electric vehicles is closely related to the driving habits of electric vehicles, battery characteristics of electric vehicles and electricity pricing mechanism. When only charging electric cars, electric vehicle charging characteristics for travel in does not affect the owner under the premise of realizing low charge fees, since most of the owners to travel in the day, and at night, so the charging characteristics of the electric car in the daytime was mainly affected by the owner of the travel habits, and in the night of the charging characteristics was mainly affected by electricity. Since most of the owners travel in the day and charge at night, the charging characteristics of the electric car in the daytime was mainly affected by the owner of the travel habits, and in the night of the charging characteristics was mainly affected by electricity. When electric vehicles participate in V2G service, they have certain energy storage characteristics. When they are connected to the grid, they tend to charge at the trough of electricity price and discharge at the peak of electricity price, so as to achieve profit. In general, as a travel tool, the primary function of electric vehicles is to meet the travel needs of car owners. Therefore, their charging and discharging characteristics are responses to the real-time electricity price of the grid without affecting the travel of car owners.

3.5. Energy Storage Users
According to the types of energy stored, energy storage can be divided into electric energy storage, thermal energy storage, natural gas energy storage, etc. Its goal is to maximize the economic benefits. Most of its methods are to purchase and store energy when the energy price is low, and sell it or use it when the energy price is high. Due to the different characteristics of different energy sources, their specific energy storage behavior characteristics are also different. For electric energy storage, due to the fast transmission speed of electricity, high energy storage price and large fluctuation of electricity price, electric energy storage charges and discharges are frequent, and there will be several charge-discharge conversions in a day according to the real-time electricity price. For thermal energy storage and natural gas energy storage, their prices change slowly, and their energy storage capacity is also high, so their power fluctuations are small. In addition, electric energy storage can also participate in the electric power auxiliary service market and gain profits by virtue of its good dynamic response ability.

4. HES Service Provider and Operators

4.1. Power Grid Company
The main business of a power grid company includes the investment, construction and operation management of regional power grids, related power transmission and distribution businesses operation; participation in the investment, construction and operation of related cross-regional power transmission and transformation and networking projects. It is also engaged in electric power purchase and sale business, responsible for electric power trading and dispatching. Besides, domestic and foreign investment and financing business, independent development of foreign trade circulation management, international cooperation, foreign project contracting and foreign labor cooperation and other businesses are included.

4.2. HES Service Provider
The hybrid energy service integrates the production, transmission, distribution, conversion, storage and consumption of various energy sources, which can realize the comprehensive management of various energy sources. By comprehensively considering the energy supply side and the energy use side, five types of businesses in the initial stage of the integrated energy market are summarized, including integrated power sales, integrated energy sales, green energy saving services, integrated demand side response and personalized customized services. The business covers many aspects, such
as micro-grid, multi-function coordination and complementarity, electric vehicle, green and energy conservation consulting, etc. With different businesses complementing each other, HES helps users to get a satisfactory energy use experience.

HES service provider with its advantages of high efficiency of energy utilization, participate in the energy market and can provide users with more personalized energy services to gain profit. At the same time, HES service providers can also set up all kinds of energy storage device to balance the peak valley load and to take advantage of the time-sharing electricity prices for boosting their profits.

4.3. HES Operators

The HES operator has the nature of natural monopoly like the power grid company, so it is bound to be supervised and regulated by the government. HES operators are non-profit energy company. In the planning, construction and operation of HES, HES operators improve the market efficiency by means organic coordination and optimization of energy production, transmission and distribution, conversion, storage and consumption process.

HES operators need to make sound energy dispatching plans according to the quoted prices of all energy market participants and ensure that the clearing prices of each energy are open and transparent. The scheduling of all kinds of energy not only needs to the balance between the input and output of the system, but also needs to ensure the highest energy utilization efficiency. In a word, the main responsibility of the HES operator is to maintain the stability of HES, promote the energy market operation, and ensure the fairness and justice of the market transactions.

5. Market players relations and competition

HES market players can be roughly divided into multi-energy supply side market players, multi-energy demand side market players and HES market service and operators according to their positions in the supply chain of the market. HES demand side subjects can trade directly with HES supply side players or trade indirectly with HES supply side players through HES service providers. Different from other markets, the transaction of HES requires the participation of transmission pipe network in most cases. Therefore, some of the funds paid by the HES demand side entities will flow to the HES transmission network investors. Money is flowing from HES demand side to HES service providers and then flow to HES supply side and transmission network investors. Therefore, the HES energy supply side and the investment pipeline network are the upstream of the market. The HES service providers are the middle of the market, and the HES energy demand side is the downstream of the comprehensive energy market.

![Figure 1. The capital flow between market players.](image)

The competition relationship mainly exists among the players in the same category, but there is less competition among the subjects in different categories. There is a strong competitive relationship between different players in the multi-energy supply side market players, while the competitive relationship between multi-energy supply side market players and multi-energy demand side market players is relatively small. For the competition among different players in the multi-energy supply side market, the competition relationship is mainly related to the substitutability or complementarity of the types of energy produced and the overlap of the users. The higher the correlation degree is, the stronger the competition relationship between the players will be. Because the quality difference of
energy products is small, the competition between different players is mainly the price competition of energy products. The higher the production efficiency, the lower the production cost, and the more obvious the competitive advantage will be.

6. Conclusion

(1) Multiple energy supply side market players: natural gas suppliers often use bilateral contracts to avoid risks. CHP unit is the core of multi-energy coupling, and its thermal power has regional monopoly characteristics. Renewable energy power stations mainly consider land cost and are often far away from load centers. The transmission pipe network has the nature monopoly attribute and need to be supervised by the government.

(2) Multi-energy demand-side market players: industrial users have great potential in temperature control load regulation; residential users are less willing to respond to price changes; both electric vehicles and energy storage users can respond to real-time electricity prices from the grid, with high-priced outputs and low-priced inputs.

(3) Market intermediaries: Power grid companies make profits mainly through the sale of electricity; HES energy service providers make money by improving integrated energy services. HES operators are regulated by the government and are primarily responsible for system stability and fair trading.

Acknowledgement

This work is supported by the Scientific and Technology Project of State Grid Shandong Electric Power Company (Key Model R&D of Energy Internet Enterprise Support, No. SGSDJY00GPJS1900057).

References

[1] MA Baoling. A theoretical and empirical study on China's gas market-oriented reform[D]. Beijing: University of International Business and Economics, 2014.

[2] WANG Bei, REN Shuyan, YANG Guirong, et al. Thoughts on marketization reform of natural gas in China[J]. Natural Gas and Oil, 2017, 35(6): 1-7.

[3] AI Qian, HAO Ran. Key technologies and challenges for multi-energy complementarity and optimization of integrated energy system[J]. Automation of Electric Power Systems, 2018, 42(4): 2-10, 46.

[4] WANG Weiliang, WANG Dan, JIA Hongjie, et al. Review of Steady-state Analysis of Typical Regional Integrated Energy System Under the Background of Energy Internet [J]. Proceedings of the CSEE, 2016, 36(12): 3292-3306.

[5] MA Huixin. Research on domestic and overseas natural gas price formation mechanism[D]. Beijing: China University of Geosciences, 2011.

[6] JI Qing. Study on the formation of North America natural gas regional pricing center[D]. Beijing: China University of Petroleum, 2017.

[7] DING Hao. The study on pricing theories and models of natural gas pipeline transmission[D]. Beijing: Beijing Jiaotong University, 2006.

[8] ZHENG Jinjun. Research on regulatory cost and regulatory revenu in the transmission and distribution price design[D]. Beijing: North China Electric Power University, 2017.

[9] ZHU Jiang, ZHENG Yunpeng, LIU Bingrui, et al. Analysis on commercial users' intelligent response behavior to tariff mechanism[J]. Modern Electric Power, 2012, 29(5): 77-80.

[10] XIONG Hugang, CHENG Haozhong, ZHANG Wenjun, et al. Analysis of the peak-valley TOU tariff effect on Shanghai residential electricity characteristics[J]. Power Demand Side Management, 2006, 8(6): 17-20.

[11] LI Mingyang, ZOU Bin. Charging and discharging decision-making model of electric vehicles and influence analysis of electricity price[J]. Automation of Electric Power Systems, 2015, 39(15): 75-81.