Technology and mode of the virtual thermal power plant in the clean heating field

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Abstract. China has the largest installed capacity of wind and solar power in the world, but winter heating in the northern region still relies mainly on coal combustion, and the current comprehensive heating scheme is still far from achieving climate change and environmental protection goals. Firstly, this paper analyses the significance of clean heating in China at the present stage, and the problems in the implementation of clean heating plan, and puts forward a virtual thermal power plant scheme based on Energy Internet. By comparing the advantages and disadvantages of the new scheme with the traditional clean energy heating scheme, it is concluded that the new scheme can not only absorb a large number of clean energy such as wind power, but also help to solve the problems of abandoned wind and solar power. In addition, it also has good economic benefits. Through the wide implementation of this scheme, the Energy Internet will lead the change of clean heating technology.

1. Introduction

Energy is an important cornerstone of human survival and development. The heating system and heating quality are closely related to people's daily life, and have a global strategic impact on social and economic development. China's energy supply still relies heavily on fossil energy, especially coal. About 70\% of the generating units are coal-fired thermal power units. At the same time, coal is the main energy source for heating in winter in northern China. In 2016, China's coal consumption was 1.888 billion tons of oil equivalent, accounting for 50.58\% of the world's total coal consumption. The proportion of coal in China's energy consumption structure has reached 62\%, far higher than the world average coal level of 30\%\textsuperscript{[1]}.

At the same time, the vast area represented by Beijing, Tianjin and Hebei have been deeply influenced by smog in recent years. Most of the viewpoints tend to think that coal-fired heating boilers and loose coal combustion are the important causes of fog and haze\textsuperscript{[2]}\textsuperscript{[3]}. In some areas, heating contributes more than 50\% to PM2.5 emissions in winter, which has become the focus and difficulty of smog control\textsuperscript{[4]}.

As heating and haze are important issues directly related to people's livelihood, the government formally put forward the promotion strategies and safeguard measures by making full use of clean heating\textsuperscript{[5]}.

The traditional clean heat source mainly includes natural gas, electricity, non-electric renewable energy and other clean energy to replace the coal. Renewable energy has great potential for heating in China. It is estimated that the potential of renewable energy heating in China can reach more than 3 billion tons of standard coal. With the rapid growth of renewable energy heating modes and the
sustained growth of solar energy heat utilization, wind power clean heating and biomass heating have begun to enter the stage of large-scale development on the basis of demonstration and application. The development and utilization of geothermal energy have shown a faster growth, and the practice of renewable energy heating has been carried out in various places according to local conditions.

Comparing these traditional clean heat techniques, as shown in Table 1[6][7].

| Technology roadmap                  | Existing problems                                                                 |
|-------------------------------------|-----------------------------------------------------------------------------------|
| Gas-fired Boiler Centralized Heating| The gas source and price fluctuates, and the initial investment and operation cost are relatively high |
| Electric heat storage and electric heating| Power supply using renewable energy is restricted by electricity market and electricity price, and its operation cost is high |
| Distributed Natural Gas Heating    | The gas source and price are greatly affected by the region                        |
| Solar thermal utilization          | Heat balance in winter and summer                                                 |
| Wind power heating                 | Increasing the capacity of distribution network and other infrastructure construction, due to the distance between wind power station and heat-using area |
| Geothermal heating                 | The operation cost is high and there are technical problems of recharge           |
| Biomass heating                    | High fuel cost leads to poor economy, lack of emission standards and limited application scope |

In addition to the advantages of clean energy, these technologies have their own shortcomings. The limitations of these technological paths lead to difficulties in promoting clean heating and insufficient social and economic benefits.

2. **Virtual thermal power plant based on Energy Internet**

Energy Internet is a new form of energy industry development, in which Internet is deeply integrated with energy production, transmission, storage, consumption and energy market[8][9]. It is a highly integrated system of energy physics and information interconnection, as shown in Figure 1.

**Figure 1.** Energy Internet.
Figure 2. Clean heating solution based on Energy Internet.

From the Figure 1, we can see that the energy scenario based on the Energy Internet is significantly different from the traditional energy scenario. The coupling between traditional energy system and information network is very low, and there is no coordinated control strategy.

Figure 3. Schematic diagram of electric heat storage engineering.

Figure 4. Operational scheme of VTPP.

As shown in Figure 2, the Energy Internet clean heating scheme proposed in this paper is as follows:
Firstly, many electric heat storage equipment in Figure 3 and Figure 4 are introduced to the larger thermal users. The so-called virtual thermal power plant (VTPP) is composed of a number of dispersed electric heat storage devices through the aggregation of the Internet[10][11]. It can also make the thermal load obtain the important functions of the virtual power plant[12], such as peak shaving and valley filling of the daily load curve, and suppressing the power demand.

Secondly, wind and solar power generation are the main heat sources of energy internet, while natural gas is the supplementary heat source. Specific schemes are determined according to the actual regional resource endowment. These clean energy resources are absorbed in real time according to the curve of supply side and demand side through the Energy Internet regulation control strategy[13].

Thirdly, instead of the traditional thermal network, the distributed Energy Micro-grid is used in many non-centralized heating application scenarios where it is difficult to build the thermal network. Especially large quantities of coal stoves are used in villages and towns, clean heat need to be applied to help people who had coal-burning stoves remove dust and soot from the air. Although the power network has been widely used, the construction of distribution network is insufficient or even missing. It is impossible to erect large grid lines in more remote mountainous areas and islands, so it can also be replaced by off-grid micro-grid.

Finally, through information physical system integration technology, these virtual thermal power plants can be controlled by demand side response control strategy of Energy Internet to participate in peak shaving and frequency modulation of power network, and as a means of stability control of each energy system.

For example, DSR control strategy can be included in the Energy Internet platform, and its control principle can be based on economic dispatching instructions obtained by linear optimization algorithm. Combining the existing operation modes of power system and thermodynamic system, the coordinated operation mode of electro-thermal system is adopted without increasing the dispatching complexity.

Electric heat storage originated in Europe in the 1950s and has a history of more than 60 years. Now electric heat storage in China is developing rapidly and given with new technical connotation: renewable energy, internet of things sensors, new heat-storing material, new DSR strategy and peak load regulation service.

Deeply promoting the above Energy Internet clean heating solutions can bring about technological changes in the field of clean energy heating. These changes are reflected in:

1. The Energy Internet scheme greatly simplifies the thermal system. After interconnecting the power network and the thermal network through the energy stations, various types of energy supply are simplified and unified.
2. Energy Internet clean heating is an effective means of peak-shaving and frequency-modulation. Thermal system combines with heat storage technology to use valley power to store heat and restrain peak power consumption.
3. Energy Internet Clean Heating Scheme can co-ordinate power, heat, natural gas pipeline network and other networks, and absorb wind power and solar energy to maximize benefits.
4. Clean heating on Energy Internet can improve energy efficiency. Energy Internet integrates each independent energy problem into a multi-energy complementary heating energy network.

Through Integrated Energy and DSR control strategy of virtual thermal power plant, heating system could become an more important facility of energy system, which can realize large-scale energy allocation with more economic and social benefits. Energy Internet is leading the development of clean heating towards innovation, coordination, green, open and sharing mode, which is one part of the reform of energy consumption.

3. Economic analysis of clean heating solutions

This paper will analyze the economy of three kinds of clean heating solutions: coal-to-electricity VS direct purchase VS energy internet:

The scenarios of the two schemes are that Jibei Integrated Energy Services Company draws a line from 10kV bus of a substation for a coal-to-electricity conversion project. It is necessary to build or
reconstruct a 10 kV special distribution line with a length of 10 km. The distribution capacity of 2MW is used for clean heating heat load. The line formed is typical distribution line.

Agreed boundary conditions:
1) The current "coal-to-electricity" Jibei company does not adopt the step tariff policy. The price of electricity is temporarily implemented according to the first-class standard of the step tariff, i.e. 0.52 RMB yuan per kilowatt-hour. If the cost of electricity purchase is considered at 0.38 yuan, the difference of the purchase price is 0.14 yuan/kilowatt-hour [14].
2) The charging fee of Hebei Province for direct power purchase is estimated at 0.03 RMB yuan per kilowatt-hour [14].
3) The Energy Internet clean energy heating scheme adopts the Energy Internet regulation control strategy of virtual thermal power plant, the demand side response cost estimation adopts the equivalent method, and the equivalent method adopts the pumping equivalent method. At present, the unit cost of typical pumped storage power station is about 8000 RMB yuan/kW.
4) The annual operating cost of the control strategy set of the energy Internet virtual thermal power plant is about 50,000 RMB yuan (including controller, communication equipment, and software usage fee, with a service life of 25 years).
5) The total investment in the construction of distribution network per kilometer is estimated at 200,000 yuan [15].
6) In the case of clean heating, the simultaneous rate of distribution network construction or renovation is close to 1, estimated according to 0.9;
7) Heating 121 days a year, 16 hours a day, and about 2000 hours a year.

Scheme A: Estimation of clean heating without heat electric storage equipment
1) Total investment: 2.1 million yuan, equivalent to about 105 yuan per kilowatt per unit cost (2 million for distribution network construction and 100,000 for operation and maintenance).
2) Annual Return: heating season charges electricity fees over the network, according to thermal load electricity consumption estimates annual over-the-network fee revenue of 108,000 yuan, 54 yuan/kW.
3) Return on investment: about 5%.

Scheme B: Estimation of Virtual Thermal Power Plant based on Energy Internet
1) Total investment: 2.15 million yuan, equivalent unit cost is about 1075 yuan/kilowatt (distribution network construction cost is 2 million yuan, operation and maintenance cost is 100,000 yuan/year, and annual use cost of energy and Internet applications is about 50,000 yuan).
2) Annual Return: Calculate the return of clean heating power by equivalent method. Assuming that only 5% of the heating capacity can be used as peak regulation and frequency regulation, it is equivalent to the function of a pumped storage power station with 1 MW. The investment of peak regulation construction can be saved up to 8 million yuan (about 8,000 yuan/kilowatt). According to the investment of 50 years of service, it is estimated to be about 160 yuan/kilowatt. Save the operation cost of peak shaving pumped storage power station (pumped energy consumption, etc.) by about 100 yuan/kW (the actual price level is closely related).
3) Return on investment: about 25%.

Table 2. Compare with Scheme A and B.

|                      | Scheme A       | Scheme B       |
|----------------------|----------------|----------------|
| Total investment     | 2.1 million yuan | 2.15 million yuan |
| Annual Return        | 0.108 million yuan | 0.52 million yuan |
| Return on investment | 5%              | 25%            |

As shown in Table 2, if the integrated energy service companies adopt the clean heating scheme A, they will invest in public welfare after considering the financing cost, without any profit, which is essentially a loss investment; while the clean heating scheme of energy internet, even considering the financing cost, is expected to take only 4-5 years to recover the cost, and the economic benefit is
remarkable; and compared with the direct purchasing electricity scheme, the energy consumption is less than that of direct purchasing electricity. The Internet clean heating scheme can absorb as much renewable energy as possible, such as wind power, and has obvious social benefits.

4. Conclusions
In summary, the Virtual Thermal Power Plant based on Energy Internet has the effect of energy saving, environmental protection and resource energy absorption with good economic benefits. Therefore, the integrated energy service providers can widely adopt the Energy Internet scheme. On the Energy Internet trade platform, it would be achievable of deep integration of thermal system and power system, more use of resource energy, the clean energy system with environment friendly and economic benefits. Energy Internet will lead the revolution of clean heating technology.

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