Economic analysis of natural gas distributed energy system for data center in Shanghai

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Abstract. Energy consumption of the data center is one of the main constraints for the development of data centers in developed regions. Shanghai has clearly defined the conditions and requirements for the construction of the data center. Through the scheme demonstration and economic analysis of gas distributed energy stations for the data center in Shanghai, the energy economy is the main factor restricting the gas distribution energy supply for the data center. Under the current background, the gas distributed energy station for the data center in Shanghai is more suitable for the construction of third-party investment operation and maintenance entities, which can significantly reduce the power usage effectiveness of the data center, although the annual energy cost of the data center increase significantly. At the same time, gas distributed energy stations need to pay attention to expand winter heat users and improve the equivalent utilization hours of energy stations to achieve greater economic benefits.

1. Introduction
With the development of information technology such as cloud computing, big data, and mobile Internet, the demand for data center keeps growing rapidly [1-2]. The average growth rate of the global IDC market scale is 17.1% from 2013 to 2017, and that of China is 37.8%. With the technological evolution and iteration of terminal-side application scenarios such as 5G and the Internet of Things, the application scenarios and market demand of the data center will be further expanded.

The power consumption of data centers accounts for about 1.8% of the total electricity consumption in China now. Due to the high energy consumption of data centers, first-tier cities such as Beijing and Shanghai, as well as developed provinces such as Zhejiang Province and Jiangsu Province, strictly control the scale of data center construction. Shanghai stipulates that the power usage effectiveness (PUE) of new data centers is less than 1.3.

In this background, construct a gas distributed energy station for data centers and use the gas distributed energy station to provide power and cold to the data center, which is a good way to reduce the PUE value of the data center[3-4], and it helps to promote the landing of data center projects.

It is generally believed that the gas distributed energy station can continuously supply energy to the data center for 8400 hours a year in the past research, and influenced by the ultra-long utilization hours, the gas distributed energy supply is economical and energy-saving[5-6]. However, it is difficult for energy stations to guarantee the energy supply time of 8400h throughout the year because the factors of climate conditions, natural gas prices, time of use (TOU) power price and so on[7-8].
Take Shanghai for example, Shanghai issued the “Guidelines for the Construction of Shanghai Internet Data Center (2019 Edition)” in June 2019, which limited the PUE of the data center, natural cold source application, gas source equivalent and energy storage and energy saving of data center. This paper takes a data center gas distributed energy project in Shanghai as an example to analyze and demonstrate the energy-saving and economy of gas distributed energy system for data center, and guide the development of similar projects.

2. Methods

PUE is one of the most critical and commonly used indicators in data center performance indicators, which is not only the key indicator of data center research, design, operation and maintenance, but also the main indicator of the government to evaluate the performance of data center. ASHRAE identified PUE of data center as the ratio of total energy consumption of data center to energy consumption of IT equipment[9], as follows:

\[
PUE = \frac{P_T}{P_{IT}}
\]

In the formula, \(P_T\) is the total energy consumption of data center, \(P_{IT}\) is the energy consumption of IT equipment in data center.

The calculation of PUE in the guidelines for the construction of Shanghai Internet Data Center (2019 Edition) is based on formula (1), which further explains and restricts \(P_T\). Revised formula is as follows:

\[
PUE = \left( \frac{P_{ele} + P_{gas} + P_{oil} + P_{cool}}{P_{IT}} \right)
\]

In the formula, \(P_{ele}\) is all the electric power supplied by the data center from the outside to ensure the operation of the data center; \(P_{gas}\) is the gas supplied by the data center from the outside to ensure the operation of the data center, which is converted into equivalent electric energy according to table 1; \(P_{oil}\) is all the oil supplied by the data center from the outside to ensure the operation of the data center, which is converted into equivalent electric energy according to table 1; \(P_{cool}\) is the external cooling supplied by the data center to ensure the operation of the data center, which is converted into equivalent electric energy according to table 1.

| Energy Type       | Amount     | Equivalent electricity (kWh) |
|-------------------|------------|------------------------------|
| electricity       | 1 kWh      | 1                            |
| gas               | 1 Nm³      | 7.131                        |
| diesel oil        | 1 kg       | 7.812                        |
| gasoline          | 1 kg       | 7.889                        |
| chilled water(7°C/12°C) | 1 MJ     | 0.02015                      |

Based on formula (2), a data center in Shanghai is taken as the model, PUE and energy supply economy are taken as the limiting conditions, and gas distributed energy supply analysis is carried out to provide reference for similar projects.

3. Power / cooling load analysis

The proposed data center has a planned building area of 18,600 m² and 3010 racks, with standard power of 5 kW/rack and 7 kW/rack respectively. The operational and maintenance office is set up in the computer room building.

3.1. Power load

The power load of the data center is related to the specific business of the data center, and the operation of the data center is stable and non-fluctuating throughout the year.

The power load demand of the data center includes IT equipment, air conditioning fans, fresh air ventilation, UPS loss, security lighting, etc. According to the data provided by the data center builder,
the annual power load of the data center is 21.86 MW while deducting the refrigeration load of the air conditioning system, of which the IT equipment power load is 18.27 MW, and the other equipment power load is 3.59 MW.

3.2. Cooling load
The cooling load of the data center mainly includes the cooling load formed by the heat dissipation of the main equipment in the computer room, the cooling load formed by the heat transfer of the enclosure structure, and the cooling load formed by the heat dissipation of the lighting and the heat dissipation of the human body.

The cooling load formed by the heat dissipation of the main process equipment in the equipment room is the most important part of the air conditioning load of the equipment room. It belongs to the stable cold load, which accounts for more than 85% of the total heat. The cold load formed by the heat transfer of the envelope structure is mainly the sum of the heat radiated by the solar radiant heat through the roof of the machine room, the wall and other envelopes, and the heat transfer caused by the temperature difference between the indoor and outdoor. It occurs in summer, and the demand accounts for less than 5% of the total cooling load. The cooling load formed by the heat dissipation of non-process equipment such as lighting heat dissipation and human body heat dissipation is different depending on the function of the room, and the cooling load of each room is also different. The fresh air cooling and dehumidification treatment of the data room adopts the air-cooled and direct-expanding fresh air unit, which consumes electric energy and therefore does not bring additional heat source to the data room.

According to the data provided by the data center builder, the data center IT cabinet racking rate is considered at 90%, and the data center IT cooling load is estimated to be 15.95 MW. The load is not significant to the external climate change. The annual fluctuation is only slightly different in a load of envelope structure. The load simulation of the data center envelope structure is carried out by the HDY-SMAD AC Load Calculation and Analysis Program. The results are shown in Figure 1, the average annual cooling load of the data center is 18.70 MW.

![Figure 1. Simulation of annual cooling load change in data center.](image)

4. Construction scheme of gas distributed energy

4.1. Installation scheme
According to 2.1/2.2 section about power load and cooling load analysis, the installation scheme of gas distributed energy is carried out. Five gas internal combustion engines which are 4400kW class will be constructed by following 10% redundancy requirements. High-temperature flue gas and jacket water from the internal combustion engine is absorbed by lithium bromide absorption refrigerator to refrigeration. Five 4.3MW centrifugal chillers are installed for that the lithium bromide absorption
refrigerator failure or the valley price. Centrifugal chillers are equipped with plate heat exchangers for natural cold source cooling in winter. A 1200 cubic meter cold storage tank is installed to meet 20 minutes of emergency cooling. The system diagram is shown in Figure 2.

4.2. Operational scheme

According to the characteristics of data center cooling load and power load, the gas internal combustion engine generator set as the main equipment, and the high temperature flue gas and hot jacket water as the heat source to drive the lithium bromide absorption refrigerator to meet the data center load demand, and the insufficient part is supplemented by commercial power.

Considering the implementation of the electric power market TOU policy in Shanghai, different operational strategies are implemented during the peak price period and the valley price period for improving the operational economy.

During the peak-level electricity price period, gas internal combustion engines + lithium bromide absorption refrigerators are used to supply power and cooling for the data center. When the load of the generator is reduced and is difficult to meet the load demand, the commercial power supply will be supplemented. When the cooling load fluctuates or the lithium bromide unit provides less cooling than the data center requires, the centrifugal chiller will be supplemented. When the high-temperature flue gas of the internal combustion engine and the jacket water provide excessive heat, the excessed high-temperature flue gas is exhausted through the electric three-way valve to ensure the safety of the system.

During the valley electricity price period, the operation mode of commercial electricity + centrifugal chiller.

According to the regulations of Shanghai, the data center uses the natural cold source time of not less than 3000h throughout the whole year, so it uses the natural cooling source for cooling the data center in the winter, both commercial power supply and the centrifugal chiller for standby.

The annual operating index of gas distributed energy station is shown in Table 2.
Table 2. The annual operating index of the gas distributed energy station.

| Item                                | Unit       | Value    |
|-------------------------------------|------------|----------|
| generation power                    | MW         | 22.005   |
| natural gas caloricity              | MJ/Nm³     | 34.38    |
| annual consumption of natural gas   | ×10⁴ Nm³   | 1928.94  |
| equivalent operating hours for the whole year | h          | 3800.93  |
| annual power supply                 | GWh        | 76.95    |
| annual cooling capacity of lithium bromide unit | ×10⁴GJ   | 95.62    |
| heat-electricity rate               | %          | 97.05    |
| overall energy utilization          | %          | 82.31    |

5. Economic analysis

5.1. Third-party construction model

Considering that a third party builds the gas distributed energy station, the static investment of gas distributed energy station is 308.08 million Yuan, including 182.86 million Yuan for equipment purchase, 36.96 million Yuan for construction engineering, 43.8 million Yuan for installation project, 29.8 million Yuan for other expenses, and 14.65 million Yuan for basic reserve. The proportion of project capital is 30%. The energy station directly supplied power supply according to the Shanghai electric power price calculation. The gas price is 2.47 Yuan/Nm³ which is decided by Shanghai natural gas power generation type, the water price is 2.0 Yuan/t according to the municipal tap water price; 2.17% for the first three years of maintenance, 4.34% for later; insurance rate is 0.25%; material cost is 8 Yuan/MWh according to the amount of power generated, and other expenses are 10 Yuan/MWh. The energy station has 12 employees, with an average annual salary of 100,000 Yuan and a welfare rate of 60%. The direct electricity tax rate is 13%; the cooling tax rate is 9% and the natural gas tax rate is 9%.

Within the above boundary conditions, the cooling price of the project is 0.463 Yuan/kWh, which is calculated by IRR=8%. At this time, the annual energy cost of the data center is 150.05 million Yuan, which increases by 20.28 million Yuan compared with the annual energy cost of the commercial power (Table 3), and the PUE value of data center is reduced from 1.43 to 1.30 (Table 3), which is accord with the regulations of Shanghai City data center.

The gas price of the energy station has a linear relationship with the cold price (Figure 3a). When the gas price is reduced from 2.47 Yuan/Nm³ to 1.42 Yuan/Nm³, the energy cost of the two schemes is equivalent, when the gas price is lower than 1.42 Yuan/Nm³, the cost of gas distributed energy station + commercial power supply is more economical.

Figure 3. Schematic diagram of gas distributed energy gas price and data center energy cost change.
5.2. Data center owner construction model

Considering that the owner of the data center builds the gas distributed energy station, in this time the data center energy consumption mainly includes the consumption of gas distributed energy station and the consumption of commercial electricity. The total energy cost of the gas distributed energy station mainly includes fuel cost, water cost, material cost, maintenance cost, labor and welfare cost, depreciation cost and financial cost, as shown in Figure 4. The average life expectancy is 76.0 million Yuan. Considering the cost of commercial electricity, the annual energy cost of the data center is 128.76 million Yuan. Compared with the commercial power supply scheme, the annual energy cost which is economical is reduced to 1.03 million Yuan (Table 3).

The relationship between the gas price and the annual energy cost of the data center is estimated in Figure 3b. When the gas price is lower than 2.53 Yuan/Nm³, the gas distributed energy station + commercial electricity combined energy supply mode is more economical.

According to the requirement of “Guidelines for the Construction of Shanghai Internet Data Center (2019 Edition)”, if the data center uses external gas to supply energy, 1Nm³ natural gas is equivalent to 7.131 kWh electron when calculating the PUE of the data center. With this regulation, the PUE of the data center is increased from 1.43 to 1.72 (Table 3).

![Figure 4. Total operating cost change of gas distributed energy.](image)

| Number | Item             | Unit       | Model 1<sup>a</sup> | Model 2<sup>b</sup> | Model 3<sup>c</sup> |
|--------|------------------|------------|----------------------|----------------------|----------------------|
| 1      | \( P_T \)        | GWh        | 187.65               | 248.26               | 205.43               |
| 1.1    | \( P_{IT} \)     | GWh        | 144.06               | 144.06               | 144.06               |
| 1.2    | \( P_{ele} \)    | GWh        | 183.66               | 106.72               | 201.44               |
| 1.3    | \( P_{gas} \) × 10³ Nm³ | - | 1928.9               | -                    |                      |
| 1.4    | \( P_{cool} \) × 10⁴ GJ | 19.79 | 19.79               | 19.79               |
| 2      | Total cost of energy supply × 10⁴ Yuan | 15004.6 | 12875.8             | 12976.2             |
| 2.1    | Electricity cost × 10⁴ Yuan | 11547.5 | 5276.0               | 12976.2             |
| 2.2    | Cooling cost × 10⁴ Yuan | 3457.1 | -                   | -                   |
| 2.3    | Other expenses × 10⁴ Yuan | - | 7599.9               | -                   |
| 3      | PUE              |           | 1.30                 | 1.72                 | 1.43                 |

<sup>a</sup> third-party construction.

<sup>b</sup> data center owner construction.

<sup>c</sup> commercial power model.

5.3. Summary

Although gas distributed energy station built by the data center can reduce the energy cost of the data center to a certain extent, according to the calculation method of PUE in Shanghai, the PUE value of
data center is increased substantially, the main reason lies in the existence of 5%~10% power consumption rate in the energy station and the high Coefficient Of Performance (COP) of electric refrigeration (5.0~7.0).

In the model of gas distributed energy station built by a third-party construction for the data center to supply cold and electricity, influenced by TOU price policy in Shanghai and winter natural cooling regulations, the equivalent utilization hour of the gas distributed energy station is less than 4000h, which increases the unit cost of energy supply of the station. In the case of ensuring the low profit of the energy station (IRR=8%), judging from the current boundary conditions of Shanghai, the annual energy cost of the data center is greatly increased (increased by 20 million Yuan), and the PUE value of the data center complies with the relevant regulations of Shanghai.

6. Conclusions and suggestions

With the evolution and iteration of technologies such as 5G technology and the Internet of Things, the market demand for data centers will continue to expand. The data center business demand in developed regions is strong, and it is the main source of data center business. In this paper, the scheme and economic analysis of gas distributed energy supply system in Shanghai are introduced, and the main conclusions are summarized as follows:

(1) The gas distributed energy station as a supporting energy supply system for the data center does help to reduce the PUE value of the data center, and the energy-saving effect is remarkable. While whether it helps to reduce the annual energy cost of the data center is debatable, and the energy economy is the main factor that restricts gas distribution stations to provide energy for the data center.

(2) According to the relevant regulations of Shanghai, the gas distributed energy station of the data center is more suitable for the construction of third-party investment operation and maintenance, which can greatly reduce the PUE value of the data center. At the same time, the energy station needs to expand the winter heat users, which can improve the equivalent utilization hours of the energy station and reduce the heating price if it is necessary to strive for a larger heating market.

References

[1] Jinkyun Cho, Byungseon Sean Kim 2011 Evaluation of air management system's thermal performance for superior cooling efficiency in high -density data centers Energy & Buildings 43 9

[2] Arman Shehabi, Eric Masanet, Hillary Price, et al 2011. Data center design and location: Consequences for electricity use and greenhouse-gas emissions Building & Environment 46 5

[3] Zheng-mao Li, Xiao-li Chen 2016 Utilization of Building-type Distributed Energy System in Data Centers. Power Generation & Air Condition 6 6

[4] Wei Liu, Hansheng Yuan 2019 Energy Unit Combined Cooling and Power Supply of data center Southern Energy Construction 6 112

[5] Jiamin Yin, Zehan Chen 2015 Application research of natural gas distributed energy system in large data center Energy Construction 2 2

[6] Jixiang Lv 2016 Energy saving and economy analysis of data center air conditioning system based on application of natural cooling technology Hefei University of Technology 3

[7] Jinghui Wang, Zhifeng Liu, Jixiang Lv, etc. 2016 Energy saving and economy analysis of data center air conditioning system based on natural cooling technology Refrigeration 44 9

[8] Suli Zhang 2016 Energy saving analysis of free cooling in chilled water system for data centers HV & AC 46 5

[9] ASHRAE 2010. PUE™: a comprehensive examination of the metric. Atlanta: ASHRAE Inc, 70,81