Evaluation of two typical distributed energy systems

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Abstract: According to the two-natural gas distributed energy system driven by gas engine driven and gas turbine, in this paper, the first and second laws of thermodynamics are used to measure the distributed energy system from the two parties of "quantity" and "quality". The calculation results show that the internal combustion engine driven distributed energy station has a higher energy efficiency, but the energy efficiency is low; the gas turbine driven distributed energy station energy efficiency is high, but the primary energy utilization rate is relatively low. When configuring the system, we should determine the applicable natural gas distributed energy system technology plan and unit configuration plan according to the actual load factors of the project and the actual factors such as the location, background and environmental requirements of the project. "quality" measure, the utilization of waste heat energy efficiency index is proposed.

1. Introduction

The distributed energy system is a comprehensive energy production system based on the cascade utilization of energy. [1] The first energy is used to drive the engine to generate electricity, and the waste heat is recycled through all kinds of waste heat utilization equipment. Distributed energy station is built in the user side, it can achieve the temperature counterpart energy supply according to the different needs of users, minimize the energy loss of all links, and ultimately achieve higher energy utilization, lower energy costs, higher energy security and better environmental performance.

At present, there are two typical distributed energy systems, which are driven by gas turbine and internal combustion engines. The working principle of the internal combustion engine is that the ignition of the fuel and air in the cylinder is mixed and compressed, and the piston drives the connecting rod and the crankshaft to drive the generator to generate electricity. After combustion of fuel, there are two forms of waste heat in combustion of fuel, such as flue gas and cylinder liner water. The temperature of medium cold water is low, and it is generally not used. Generally speaking, the power generation efficiency of internal combustion engine can reach 30%-40%, and the thermal efficiency of cylinder liner can reach 25%, and the thermal efficiency of flue gas (the temperature of exhaust gas condenses from 400 to 120 degrees) can reach 18%-25%. [2]

The working principle of gas turbine is to form high temperature and high-pressure gas by burning fuel inside the machine. High temperature and high-pressure gas enters the expansion wheel to expand and do work, and heat energy is converted to mechanical power generation. The afterheat of a gas turbine is only a form of smoke exhaust. Therefore, the rest of the thermal utilization system is simpler than the internal combustion engine, which can generate hot water and steam through the waste heat boiler, and can also directly produce cold water and hot water through the absorption cold and warm water unit. [3]
Generally speaking, gas engine is mostly used in building distributed energy station, and the power consumption of gas turbine is large, and it is mostly used in large-scale building cooling heating and power cogeneration system and district cooling heating and power cogeneration system.

2. Sub goal of "Quantity"

"Quantity" sub goal is mainly based on the first law of thermodynamics. The comparison between input and output of distributed energy system is made. The direct influence factors are power generation, cold/hot output and so on. The key evaluation indexes mainly include primary energy utilization ratio, waste heat recovery efficiency and so on.

The primary energy utilization ratio is the ratio of the system terminal to the energy consumption, and the input energy is traced back to a single energy source. The primary energy efficiency includes the production and transportation of energy, which is the application of the first law of thermodynamics. The definition of the primary energy utilization ratio is:

\[
\eta_s = \frac{\sum P + \sum Q_h + \sum Q_c}{B \cdot Q_{ar.net}}
\]

In (1), P represents the system output electrical power, including the original motive and the output power of the steam turbine; \(Q_h\) represents the heat output per unit time, including steam, air-conditioned hot water, and domestic hot water; \(Q_c\) represents the cold output of system unit time; B represents fuel consumption per unit time system; \(Q_{ar.net}\) represents the low calorific value of fuel.

The waste heat is the energy that is not used in the energy use equipment under certain economic and technical conditions, that is, the surplus and abandoned energy. It includes seven kinds of high temperature waste heat, cooling medium waste heat, waste steam waste heat, high temperature products and slag waste heat, chemical reaction waste heat, combustible waste gas, waste heat and waste heat, and high-pressure fluid residual pressure. Waste heat recovery and utilization is an important way to improve economy and save fuel. The availability and value of waste heat is determined by two aspects of its output and quality.

The amount of waste heat is the amount of remaining heat. The quality of the waste heat is the quality of the waste heat. It can be characterized by its temperature, pressure and the medium carrying the heat. The higher the waste heat grade, the greater the quantity, the greater the availability and the value of it. The availability and value of waste heat are not equal to the effect of waste heat utilization. The former refers to the quality and properties of the waste heat itself, which only indicates the availability of the residual heat, but does not indicate the effectiveness of the waste heat utilization. The latter is not only determined by the quality of the waste heat itself, but also depends on the location, environment and utilization of waste heat, which is determined by the object and condition of using waste heat. For example, the use of heat as a heat is better than being used as a function. In the distributed energy system, the residual heat is mainly from the original motive of the flue gas heat, the corresponding residual heat recovery efficiency expression \(\eta_{wh}\) is as follows:

\[
\eta_{wh} = \frac{\sum P_{wh} + \sum Q_{wh,h} + \sum Q_{wh,c}}{B_{fg} \cdot h_{fg}}
\]

In (2), \(P_{wh}\) represents the power generation power of the system using waste heat; \(B_{fg}\) represents the smoke discharge per unit time original motive; \(Q_{wh,h}\) represents the heat output produced by the system using the residual heat; \(Q_{wh,c}\) represents the cold output generated by the system using residual heat; \(h_{fg}\) represents the enthalpy of exhaust smoke from the original motive.

3. Sub goal of "Quality"
The "quality" of sub goals mainly from the second law of thermodynamics of energy distributed energy system of the availability of energy transfer and conversion, reveal the energy consumption and the use of size, position and cause, the work capacity of energy as a criterion, namely the system of exergy analysis. The ratio of the system exergy efficiency is defined as the income and expenditure of exergy system of exergy, exergy utilization degree of the main point, from the quality of utilization of exergy was evaluated. The key evaluation index of quality is the main target of exergy efficiency, waste heat utilization system of exergy efficiency.

The definition of the system of exergy efficiency is: in the transmission system or equipment and energy conversion process, the total exergy output of the system (i.e. being used or exergy and the total exergy and exergy return) system input (i.e. fuel combustion heat exergy generated by the ratio). Exergy efficiency is also known as the two-exergy consumption rate, relative to the primary exergy utilization rate of the system is concerned, how to use energy more reasonable standard, it is in the nature of the exergy utilization degree of evaluation index. For the distributed exergy cogeneration system, the exergy efficiency $\eta_{ex}$ for expression is:

$$\eta_{ex} = \frac{\sum P + \sum A_c \cdot Q_c + \sum A_h \cdot Q_h}{\sum BO_{net}}$$ (3)

In (3), $A_c$ represents the cooling efficiency in Kano cycle; $A_h$ represents the circulation efficiency of heat in Kano.

In the calculation of system exergy efficiency, cold and heat energy and electricity relative income, low sensitivity, so the introduction of "waste heat utilization of exergy efficiency" concept, to the extent of waste heat cascade utilization evaluation of distributed energy system in a more intuitive. The definition of energy efficiency $\eta_{yex}$ for waste heat utilization is:

$$\eta_{yex} = \frac{\sum P_{wh} + \sum A_c \cdot Q_c + \sum A_h \cdot Q_h}{B_{fl} \cdot h_{fl}}$$ (4)

4. Practical application

In order to evaluate two typical distributed energy stations driven by internal combustion engines and gas turbines, this paper selects four typical energy stations as the object of evaluation. Among them, distributed energy station A and distributed energy station C are gas turbine driven, distributed energy station B and distributed energy D are internal combustion engine driven, installed capacity is distributed energy station C>A>B>D. The installed modes of each distributed energy station are as follows:

The distributed energy station A is equipped with two gas turbine units for the LM2500+G4 type gas turbine of the GE company of the United States. Two heat recovery boilers and a 25MW turbo generator set are equipped with "two dragging one" mode. The energy station supplies cold, hot (industrial steam, hot water) and electricity to nearby industrial park enterprises.

The distributed energy station project B equipped with 5 sets of 4.4MW gas engine, take the cold and hot set of principles, using gas generator for flue gas temperature after more than 300 DEG to 500 DEG and 95 DEG C high temperature flue gas cylinder water drive unit produces hot water type lithium bromide cold water below 6.7 degrees centigrade or 87.8 degrees Celsius hot water hot and cold medium water and hot water for air conditioning to the park. The water storage and chiller units are used as the peak load regulating equipment for cold load. The gas boiler is equipped with the heat storage device as the peak load equipment for heat load, and the linkage operation equipment of the screw air compressor and the gas storage tank is set up.

The distributed energy station C is equipped with two GE (general) gas turbine generator sets, which is the LM6000 series of GE company. Two waste heat boilers and two double pressure pump steam turbines and their generators. The energy station adopts the "one - one" way, and the system is pumped to the surrounding industrial park.
The energy station D has built 2 * 4.044MW class internal combustion unit, 2 flue gas hot water lithium bromide units, 1 centrifugal chillers, 1 sets of energy storage devices, cold and hot pipe network and two pumps and other auxiliary facilities.

After the field test, the data of the four energy stations' running data are shown in Table 1.

**Table 1 Running data of distributed energy station**

| Distributed energy station | A     | B     | C     | D     |
|----------------------------|-------|-------|-------|-------|
| Fuel consumption per unit time(kg/s) | 3.48  | 1.04  | 5.12  | 0.41  |
| Thermal output of system unit time(kW) | 25857 | 6670  | 76708 | 2520  |
| Cold output of system unit time(kW)    | 0     | 8577  | 0     | 3432  |
| Output power(kW)                   | 79006 | 20175 | 102052| 7620  |
| Waste heat power generation power(kW) | 17708 | 0     | 38373 | 0     |
| Smoke discharge per unit time(kg/s)  | 180.00| 30.52 | 418.75| 11.4  |

As described in the second and third section, the evaluation of the "quantity" and "quality" of each distributed energy station is shown in Table 2:

**Table 2 System evaluation of distributed energy station**

| Distributed energy station | A     | B     | C     | D     |
|----------------------------|-------|-------|-------|-------|
| Primary energy utilization | 68.46%| 74.40%| 77.03%| 72.71%|
| Recovery efficiency of waste heat | 48.41%| 84.86%| 53.36%| 66.93%|
| Exergy efficiency          | 60.36%| 45.75%| 55.38%| 46.11%|
| Waste heat utilization of exergy efficiency | 34.61%| 11.69%| 30.06%| 13.67%|

From the primary energy utilization, the distributed energy station C>B>D>A. This is because the industrial heat load of C is better and the thermal efficiency is higher. The primary energy efficiency of B and D driven by the internal combustion engine is higher than that of the internal combustion engine, because the power generation efficiency of the internal combustion engine is high, and the large amount of heat carried by the cylinder water is utilized.

From the efficiency of waste heat recovery, the distributed energy station B>D>C>A, this is because the waste heat of the distributed energy station B is fully utilized, and the heat of living hot water is also used in addition to the traditional cold and hot electricity. The internal combustion engine for B and D distributed energy station heat recovery efficiency driven higher than A and C distributed energy station with gas turbine driven, this is because, in the internal combustion engine power, in addition to smoke away large amounts of heat, water jacket also took away a lot of heat, so that heat recovery system efficiency.

From the use of exergy efficiency and waste of exergy efficiency, distributed energy station A>C>D>B, this is because the heating load of A is low, the system has a high-quality heat energy, so the system of energy efficiency. In the internal combustion engine heat utilization, flue gas heat and water jacket heat of poor quality, cannot produce high-quality energy, so the system of exergy efficiency is low.

It can be seen that the primary energy utilization of distributed energy stations depends on the degree of energy utilization, the higher the demand for heat load is, the higher the primary and secondary energy consumption is, the higher the primary energy utilization rate of the system is, and the higher the recovery efficiency of the waste heat. Although the internal combustion engine power efficiency is higher, but the jacket water and cold water in the heat taken away a lot, this part of heat, can only be
achieved by low grade, so the system of exergy efficiency and waste heat utilization of exergy efficiency is low.

5. Conclusions
For a gas distributed energy station which is built at the load terminal, the choice and configuration mode of different users is different, depending on the user's cold, heat and electricity demand structure. Generally speaking, the operation of gas and internal combustion engines needs medium and low-pressure gas and gas engine driven CHP combined heating system, which is suitable for urban high-speed rail stations, hospitals, shopping malls, office buildings and other places with stable load, air conditioning, heating, steam and other loads. The operation of gas turbines needs high pressure gas, and the gas turbine driven CHP system is suitable for the public places with relatively large load demand on the urban fringe and enterprises with stable electric load, steam load and hot and cold industrial load demand.[6] According to the user's demand for cold, heat and electricity, it is very important to configure the right unit to meet the needs of the joint supply system, and it is also the key to decide whether the combined supply system is successful or not. The development of gas distributed energy will become an important part of adjusting and optimizing energy structure and building a safe, stable, economic and clean modern energy industry system.

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