Analysis on the natural gas distributed energy system scheme of a hospital complex in Xi'an

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Abstract. Natural gas distributed energy systems (NGDESs) have the advantages of peak load shifting and good economic benefits suitable situations. In the paper, the energy processes of NGDESs for large-scale hospitals in Xi'an are analyzed firstly, by considering the current policy of “grid-connected with no power injection” and the characteristics of prime mover, residual heat utilization equipment and energy consumption in hospital buildings. Secondly, the hourly cooling, heating and electrical loads of a hospital complex in one year are simulated by DesignBuilder software. Based on the further analysis of hourly loads in the year and its changes on typical days, the main devices of the NGDES are chosen optimally. The number of internal combustion engines is determined after comparing their economic benefits of different number of internal combustion engines. Finally, through comparing their initial investment and annual operating cost of the NGDES with that of the separating supply system, the results show that the annual average energy utilization rate of the NGDES is 80%, and its energy saving rate is 34.4% compared with that of the separating supply system.

Keywords: Natural gas distributed energy system (NGDES); Energy process; Cooling, heating and electrical loads; annual average energy utilization rate; Hospital complex

1. Introduction

Due to the importance of energy structure optimization and environmental protection day by day, and the advantages of natural gas distributed energy system (NGDES) such as high energy utilization efficiency, peak load shifting and good economic benefits, NGDESs has been widely used [1,2]. There are some studies on optimal equipment sizing and operational strategy of NGDESs [3-5]. On the other hand, with the improvement of medical technology and great concern on people health, especially in China, energy consumption of hospital complexes rises continuously and is 1.6 to 2 times than that of
other public buildings[6]. Large amounts of energy and its various load stability are needed in hospital complexes, so NGDES is suitable for hospitals. However, limited research on NGDES used in hospitals was reported [7-9]. In particular, the application of NGDES is still in its infancy in China, and there are many problems such as insufficient operating time of practical NGDESs and mismatch between operating loads and design loads [5].

Based on above description, optimal design and operating adjustment of NGDES used in hospital complexes in China need to be further studied. In this paper, a reasonable scheme for the NGDES applied in a hospital in Xi’an is investigated according to the energy consumption characteristics of this hospital complex and different scheme comparison from economic benefits and energy efficiency after simulating and analyzing its hourly cooling, heating and electrical loads.

2. Load simulation and analysis
Energy consumption of hospital complexes mainly includes heating, ventilation, air conditioning (HVAC), hot water, steam, lighting, medical and power facilities, etc. Among them, the consumption of HVAC, hot water and steam takes a large share. In this chapter, DesignBuilder software is used to simulate the hourly cooling, heating and electrical load of a hospital complex in Xi’an[10].

2.1 Electrical load
The simulation results of the hourly electrical load of the hospital complex in three typical days are shown in Figure 1. As demonstrated in Figure 1(a), electrical load in summer is significantly higher than that in other seasons, and electrical load in winter is slightly higher than that in intermediate months. The peak value is 24502 kW. It also shows that the typical daily peak value occurrence periods in summer, winter and intermediate months are almost uniform, and the pattern of hourly variation is similar. The time distribution curve of the annual electrical load in the hospital complex is further analyzed, and the results are shown in Figure 1(b). It can be found that when the electrical load value is greater than 50% of the peak value, the proportion of time is less than 7%; the maximum time proportion is 37.4% when the electrical load value is between 10% and 20% of the peak value. In the whole year, 68.4% of the electrical load value is less than 30% of the peak value.

2.2 Cooling and heating loads
The simulation results of the hospital complex’s hourly cooling and heating loads in two typical days are shown in Figure 2. Maximum cooling and heating loads are 34530 kW and 20629 kW, respectively. Figure 2 shows that the minimum cooling load on the typical summer day is 4417 kW, and the cooling load is greater than 10000 kW during working time (8:00-18:00). The minimum heating load on the typical winter day is 1070 kW, and the heating load is greater than 8500 kW during working time (8:00-18:00). Furthermore, the time distribution of annual cooling and heating loads in the hospital complex is calculated. It is founded that 77.1% cooling load of the whole year is less than 14.5% of the annual maximum cooling load, and 55.7% heating load of the whole year is less than 24.2% of the annual maximum heating load.

2.3 Domestic hot water load
The hospital has a large amount of steam and hot water requirement for health care (ward bath,
disinfection and sterilization of medical items, laundry, food supply, etc.). Domestic hot water load fluctuates little over a year, so the selection of equipment can be decided referring to hourly hot water load curves in a typical day. Using hourly load coefficient method, the calculation results are shown in Figure 3. The domestic hot water load fluctuates severely in the day and is more than 1565 kW in the course of the working time. The minimum load demand is 137 kW while the maximum is 4577 kW.

3. Energy process and equipment configuration

According to the analysis of the hospital complex loads, it is found that the domestic hot water load is needed and relatively stable throughout the year, and that the cooling, heating and electrical loads of the hospital complex are fluctuated greatly. Considering the poor partial load characteristics and more cost and lower efficiency of gas turbines to internal combustion engines, therefore NGDESs with internal combustion engines as the core of power generation equipment are a good approach for large-scale hospitals. The residual heat of the generator can be used for heating and cooling and domestic hot water loads.

In view of the relative stability of daily domestic hot water load, the residual heat of the independent internal combustion engine is available. Besides, using the regenerative tank controlled by the system to adjust the fluctuation of daily hot water load. During heating and air conditioning seasons, extra engines are set up to meet the demand of cooling and heating loads in the hospital complex by using residual heat. The conventional operation mode of "following electrical load" or "following heating load" of NGDESs does not match hospitals, because most of the hospital complexes’ annual load values are far less than the peak values, and the policy on “grid-connected with no power injection” is restricted. Therefore, this paper proposed a matching operation scheme
that considered not only the full utilization of residual heat under the condition of “basic power load” but also the peaking demand of the system. The energy process is shown in Figure 4, which is composed of gas internal combustion engine + absorption heat pump + flue gas/water heat exchanger + water-water heat exchanger + equipment for peak load shaving.

![Figure 4. Energy process of NGDESs for large-scale hospitals](image)

### Table 1. The technical parameters of the power generation equipment of the NGDES

| Serial number | Equipment                          | Technical parameter                                           | Quantity |
|--------------|------------------------------------|--------------------------------------------------------------|----------|
| 1            | Natural gas internal combustion engine | Rated power generation is 1562 kW, power generation efficiency is 41.7%. | 4        |
|              |                                    | Heat dissipation of high temperature cooling water is 690kW, heat dissipation cooling water is 249kW, power is 22kW |          |
| 3            | High temperature cooling water heat exchanger | Heat exchange is 755kW | 1        |
| 4            | Flue gas/water heat exchanger       | Heat exchange is 920kW, flue gas temperature is 415/120°C, supply and return water temperature is 80/60°C | 1        |
| 5            | Flue gas hot water type direct-fired unit | Cooling capacity is 1454kW, heating capacity is 1278kW, power is 5.3kW | 3        |

In general, the generator capacity of CCHP system in civil building is not more than 30% of its maximum designed electrical load \[^{(11)}\], so as to make the generator have a higher load rate during grid-connected operation. When the number of internal combustion engines increases from 2 to 4 and 6, the proportion of the engine power generation to the peak electrical load of the hospital complex increases from 12.75% to 25.50% and 38.25%, respectively. Furthermore, in order to explore the impact of different internal combustion engine numbers on the economic benefits of the system, the annual operating cost and initial investment of 2 to 6 internal combustion engines and their supporting
equipment are compared. The specific calculation results are shown in the Chapter 4. The results show that within the configuration of 6 internal combustion engines, the total annual cost decreases gradually with the increase of the engines. Based on the two points above, 4 internal combustion engines are finally determined as the optimal number.

According to the energy process of the NGDES and the hourly load variation characteristics of the hospital complex, the main equipment model configurations are shown in Table 1.

4. Economic and energy efficiency analysis

The economic comparison between the NGDES schemes under different number of internal combustion engines are shown in Figure 5 and it can be seen that the total annual cost gradually decreases with the increase of internal combustion engines. At last, four internal combustion engines are selected.

![Figure 5. Economic comparison of different number of internal combustion engines](image)

In order to further illustrate the economic benefits of the optimized NGDES, its initial investment and annual operation cost are compared with that of a separating supply system. Although the initial investment of the NGDES is 55.768 million Yuan higher than that of the separating supply system, the annual operation cost is 8.468 million Yuan lower. So, its incremental investment recovery period is 6.6 years.

Further, the annual average energy utilization rate of the NGDES is 80%, more than 70% which is the requirement of the Technical Specifications for Combined Cooling, Heating and Power Engineering (CJJ145-2010) [11]. The energy saving rate of the NGDES is 34.4% compared with that of the separating supply system, and its energy saving effect is remarkable.

5. Conclusions

In this paper, the technical scheme of NGDESs is studied by load calculation, simulation, cost-benefit calculation and comprehensive analysis of a hospital complex in Xi'an. The main contents and results are as follows.

On the premise of "grid-connected with no power injection" policy, it is recommended to adopt the energy process as “gas internal-combustion engine + absorption heat pump + flue gas/water heat
exchanger + water-water heat exchanger + equipment” for peak cut for NGDESs of large-scale hospitals.

In view of the hospital complex in Xi’an, the results of load simulation show that 68.4% of the whole year electrical load is less than 30% of the annual maximum electrical load in the hospital complex. 77.1% of the whole year cooling load is less than 14.5% of the annual maximum cooling load in summer. 55.7% of the whole year heating load is less than 24.2% of the annual maximum heating load in winter.

When the capacity of the configured internal combustion engine is not more than 30% of the maximum designed electrical load, the total annual cost decreases gradually with the increase of the engines.

By means of comparing the initial investment and the annual operating cost of NGDES with the separating supply system, it is concluded that the annual average energy utilization rate of the NGDES is 80%, and its energy saving rate is 34.4%.

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