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Research Paper

Optimal design of installation capacity and operation strategy for distributed energy system

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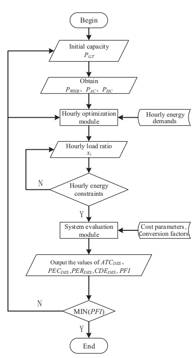
HIGHLIGHTS

- An optimization model of DES for multiple building complexes is proposed.
- The minimum performance factor indicator (PFI) is taken as the objective function.
- The hourly energy balance between supply and demand is chosen as constraint.
- Optimal installation capacity and operation strategy can be obtained by the model.

GRAPHICAL ABSTRACT



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ABSTRACT

The economic and environmental performances of distributed energy system (DES) are closely dependent on its design and operation strategy. Based on the framework of simple cycle gas turbine, an optimization model of DES is built for multiple building complexes in this paper, where the minimum performance factor indicator (PFI) is taken as the objective function and the hourly energy balance between supply and demand is chosen as constraint. Not only the problem of the configuration for installation capacity can be solved, but the concept of time scale is introduced in the process of operation optimization, to minimize energy waste and achieve maximum economic and environmental benefits. Furthermore, an illustrative case study about capacity design and operation strategy of DES in one financial center is given to present the effectiveness of the proposed model. The result shows that the optimal installation capacity is 23.77 MW while satisfying the energy demand of the terminal users. In comparison to separation production system, the primary energy consumption and carbon dioxide emission can be significantly reduced and the overall economy is improved when the DES adopts optimal installation capacity and operation strategy, which can provide theoretical reference for the actual design and operation of DES.
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1. Introduction

The distributed energy system (DES), also known as combined cooling, heating and power (CCHP) system, is composed of three parts, namely power generation unit, refrigeration unit and heating unit. The power generation unit (PGU) is driven by fuel and produces the electricity on site to satisfy power demand of terminal users. Simultaneously, the waste heat rejected from the PGU is utilized for cooling and heating demand, which avoids energy waste. Compared with the traditional separation production (SP) system, DES is installed flexibly near the users in a more compact and

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Nomenclature

$C_{capital}$	annual capital cost (10^4 yuan)
$C_{operation}$	annual operational cost (10^4 yuan)
$C_{maintenance}$	annual maintenance cost (10^4 yuan)
C	cost of energy (yuan/Nm^3 or yuan/kW h)
cc	initial capital cost (yuan/MW)
G	natural gas consumption (Nm^3)
E	electricity (kW h)
Q	heat (kW h)
I	interest rate
N	service life of equipment (year)
P	installation capacity (MW)
n	number of equipment
x_i	hourly load ratio
r	low heat value (kJ/kg or kJ/Nm^3)

Greek symbols

η	efficiency
α	standard coal conversion factor (kgce/Nm^3 or kgce/kW h)
β	CO_2 emission conversion factor (kg/Nm^3 or kg/kW h)
γ	thermal to electricity ratio

Subscripts

GT	gas turbine
GB	gas boiler
WHB	waste heat boiler
EC	electric chiller
AC	absorption chiller
HC	heating coil
E	electricity
T	thermal
ng	natural gas
gp	grid power
sc	standard coal
c	cooling
h	heating
i	Hourly

Abbreviations

DES	distributed energy system
CCHP	combined cooling, heating and power
SP	separation production
ATC	annual total cost (10^4 yuan)
PEC	primary energy consumption (tce)
PER	primary energy ratio
CDE	carbon dioxide emission (ton)
PFI	performance factor indicator
PGU	power generation unit
FEL	following the electric load
FTL	following the thermal load
COP	coefficient of performance

decentralized form, satisfying different energy demands. Because of high energy efficiency, significant effect of energy saving and emission reduction, countries around the world have made great efforts to spread DES in recent years, in order to make the entire energy industry economic, safe, efficient and environmentally friendly [1–3]. However, challenges and opportunities coexist. There are some technical problems hindering the development of DES, of which the most important problems is optimization of capacity and operation for DES. Thus, whether the designed capacity is reasonable and the operation strategy is scientific, greatly affects the actual efficiency and economic benefits of the system [4–6].

To make rational use of the DES, many researchers have been devoted to relevant studies, and proposed many optimization models of DES with different optimization targets or objects. Through optimization models, these studies aim to obtain the rational equipment capacity and optimal operation strategy of DES, so as to fully achieve its advantages of being economic, environmentally friendly and efficient. Rong et al. [7] applied the Tri-Commodity Simplex algorithm to optimize the CCHP system, which minimized the costs of production and carbon dioxide emission to the largest extent. Wang et al. [4] optimized capacity and operation for CCHP system by genetic algorithm to maximize energy-saving, cost-saving and environment-protecting potentials. Liu et al. [8] used a matrix modeling approach to optimize CCHP system, which was viewed as an input–output model. Biezma et al. [9] compared a variety of building energy schemes based on the economic and energy consumption evaluation criteria. The results showed that the optimal energy scheme under different evaluation criteria would be different. Arcuri et al. [10] built a mixed integer programming model for optimal design of trigeneration in a hospital complex, which could determine the optimal designed capacity and optimal operation strategy simultaneously. Lozano et al. [11] analyzed the redundancy design of CCHP system, aiming to minimize annual total cost by optimizing facilities scheme and operation strategy in building CCHP system. Cho et al. [12] and Mago et al. [13] proposed the optimization of CCHP system based on operational cost, primary energy consumption (PEC), and carbon dioxide emission (CDE). Ren et al. [14] studied the optimal design of CCHP systems for building complexes in five major climate regions of China, taking maximum economic benefit as the optimization target. Zhou et al. [15] developed a general optimal design model for DES in China, which could obtain optimal technology scheme and equipment capacity, according to the characteristics of terminal energy demand and the primary energy supply situation in the region. Tichi and Ardehali [16] focused on energy price policies so that they examined the effects of current and future energy price policies on optimal configuration of CHP and CCHP systems in Iran, based on particle swarm optimization algorithm. In addition, some researchers paid more attention to environmental benefits and proposed models of DES based on renewable resources (e.g. solar energy or biomass) [17–20].

Through analysis of the researches mentioned above, it can be seen that most of the optimization models proposed are only suitable for optimizing capacity and operation of CCHP systems in single buildings, such as hospitals, hotels, industrial parks, etc. Only a few optimization models can be applied to DES of various building complexes. Besides, these models rarely introduce the concept of time scale during the process of optimizing the operation strategy, which only constrain the energy balance between total energy supply and demand for a certain period of time, regardless of hourly fluctuation of terminal energy demand. Therefore, these models just roughly solve the problem of matching the total amount of energy supply and demand at a certain period, while failing to accurately satisfy the hourly matching between energy supply and demand. On the basis of optimized result obtained by these

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