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Sensitivity analysis of energy demands on performance of CCHP system

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ABSTRACT

Sensitivity analysis of energy demands is carried out in this paper to study their influence on performance of CCHP system. Energy demand is a very important and complex factor in the optimization model of CCHP system. Average, uncertainty and historical peaks are adopted to describe energy demands. The mix-integer nonlinear programming model (MINLP) which can reflect the three aspects of energy demands is established. Numerical studies are carried out based on energy demands of a hotel and a hospital. The influence of average, uncertainty and peaks of energy demands on optimal facility scheme and economic advantages of CCHP system are investigated. The optimization results show that the optimal GT's capacity and economy of CCHP system mainly lie on the average energy demands. Sum of capacities of GB and HE is equal to historical heating demand peaks, and sum of capacities of AR and ER are equal to historical cooling demand peaks. Maximum of PG is sensitive with historical peaks of energy demands and not influenced by uncertainty of energy demands, while the corresponding influence on DH is adverse.

1. Introduction

CCHP (combined cooling, heat and power) is an energy supply system that produces cooling, heat and electricity simultaneously from a single source of fuel. Because this new type of energy supply system has advantages in aspects of energy saving and environment protection, the study and application of CCHP in China increase speedily for the urgent needs of energy saving and environment protection.

The knowledge of the performance of CCHP system is necessary for developing and spreading this technology. Parameter sensitivity analysis is an important method to understand the characters of CCHP system, and is helpful to the facility evaluation, optimization of sizing and operation strategy of the system. Parameters sensitivity analysis of CCHP system studies the influence of the change of parameter on the optimization results of the system. There are sensitivity analyses about fuel price, electricity price, efficiency of generator etc. [1–3]. The sensitivity analysis of energy demands on performance is necessary to study since the main aim of energy supply system is to meet the energy demands, and which are key constants in the constraints of the optimization model.

In the aforementioned sensitivity analysis, electrical price, fuel price, etc. are considered as known quantities. However, it is difficult to give accurate values to energy demands because they depend on uncontrollable factors such as weather. A rational description of energy demands is needed before the sensitivity analysis. Normally, a time series of historical energy demands are used to represent the energy demands of a building. Hawkes studied the influence of sampling time interval of energy demands on the optimization of micro-cogeneration system [4]. Nowadays, hourly sampling energy demands are mostly adopted in the study of CCHP system. Piacentino [5] and Cardona [6] studied the influence of variable energy demands on performance of CCHP system with data of energy demands of 8760 h. However, their model can only be used for simple facility scheme which is optimized just from a small set of layouts. There are 26280 values of three kinds of energy demands in the 8760 sampling times. The amount of so many values will lead to dimension disaster in the MILP (mixed-integer linear programming) integrated optimization model of facility scheme and operation strategy, which is the optimization model commonly used nowadays [7,8] and is adopted in this paper.

It is impossible to do analysis of each datum of energy demands. Takahshi [9] uses five variables calculated from 1152 energy demand values to describe the energy demands of cogeneration system. Similar method is adopted in this paper to describe the energy demands. In the MILP model of CCHP system, the hourly sampling energy demands of a year are not inputted directly. The averages of energy demands of each of daily sampling times of each season (or month) compose the energy demands patterns of representative day. Yun uses the energy demands of representative days in the optimization model [10]. In fact, energy demands of same season and same hour of different day present uncertainty and most of them are not equal to the average. Gamou uses a normal distribution function to describe the uncertainty of energy demands of

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Nomenclature

GB	gas boiler	T_m	days of *m*th season
GT	gas turbine	ΔT	duration of sampling time
HE	heat exchanger	Co	operation cost of sampling time
AR	absorption refrigerator	R	capital recovery factor
ER	electrical refrigerator	i	interest rate
EC	electricity to drive the CCHP system	v	salvage value to initial capital cost
PG	purchased electricity	λ	ratio of maintenance to initial capital
Q	heating demands	γ	unit price of facility
C	cooling demands	f	*f*th facility
E	electricity demands	N	capacity of facility
D	energy demands	n	service life of facility
q	index of heating demands	PF	unit price of natural gas
c	index of cooling demands	F	natural gas flow rate function
e	index of electricity demands	PP	unit price of purchased electricity
P	probability density function	PG	purchased electricity power function
m	*m*th season	d	combination of energy demands
k	*k*th sampling time	OP	output of facility
x	design variable of CCHP	IP	input of facility
y	continuous operation variable	η	characteristic parameter of facility
z	integer operation variable	δ	on-off status of facilities
COST	annual total cost	μ	characteristic parameter of facility
CC	annual fixed charge		

each sampling time [11]. In addition, historical peaks of energy demands are also considered in most MILP model of CCHP.

So, energy demands can be described by average, uncertainty and historical peaks. Qualitative sensitivity analyses of them about a hotel and a hospital are carried out in this paper to study their respective influence on sizing and economic feasibility of CCHP system. If one facility capacity or economic index is sensitive with one of the three aspects, the aspect shall be paid more attention when dealing with the index, otherwise, attention and more accurate is unnecessary. And it is helpful to acknowledge the relation between the performance of CCHP system and energy demands.

2. CCHP system configuration

The CCHP system adopted is shown in Fig. 1. The key facility of the system is the gas turbine, which is widely adopted in CCHP system for its characters of high efficiency, low noise and emission, high feasibility, stability, etc.

As far as the system in Fig. 1 is concerned, gas turbine (GT) generates electricity and heat simultaneously; heat from GT is used for heating through heat exchanger (HE) or cooling through absorption refrigerator (AR), or exhausted to atmosphere by exhaust heat exchanger (DH). Gas boiler (GB) and HE meet the heat demand jointly; electrical refrigerator (ER) and AR meet the cooling demand jointly; GT and purchased electricity (PG) supply all the electricity needed in the system.

3. Model of CCHP optimization

The optimization model of CCHP system is composed of design variables *x* and operation variables *y*, *z*. Design variables *x* consist of facility capacities, maximum purchased gas and maximum purchased electricity, which are determined at the planning stage. Operation variables *y* and *z* indicate the operation status, and *y*, z represent continuous variables and integer variables, respectively. The relation between the two types of variables is complex and an integrated optimization model is necessary to optimize all the variables simultaneously.

3.1. Description of energy demands

Energy demands are described by averages, uncertainty and historical peaks. Average energy demands are described by energy demands patterns of representative days. Historical peaks of energy demands are just three constants. The energy demands are most difficult to describe when uncertainty is considered.

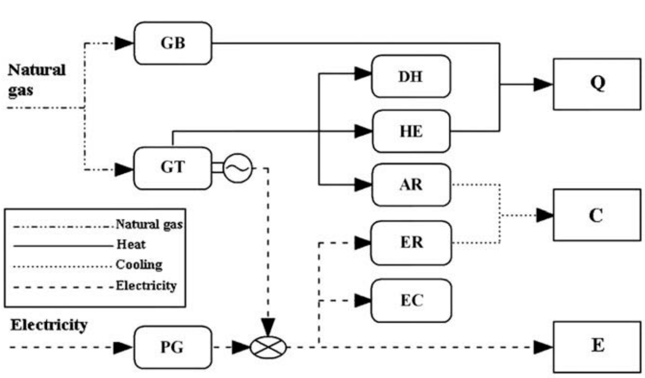

Fig. 1. Schematic diagram of gas turbine cogeneration system.

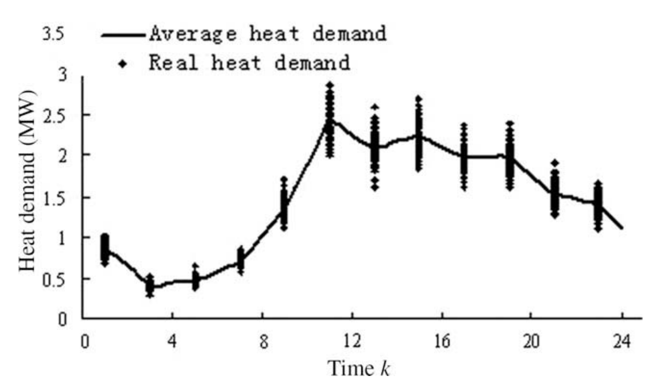

Fig. 2. An example of real data of the heating demands.