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Research Paper

Study on heat and power decoupling for CCHP system: Methodology and case study

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HIGHLIGHTS

- A weak decoupling method is proposed to optimize the CCHP system.
- A matrix model including energy input, conversion, storage and output is introduced.
- The integrated performance obtained by AHP is employed as the optimization objective.
- Performances of three operating strategies are presented and compared.

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ABSTRACT

Distributed energy systems have advantages in mitigating environmental problems and improving energy utilization efficiency. However, the modelling and simulation of such kind system tend to apply the separate modelling method for various sub-systems. Based on the graph and matrix theory, this paper proposed a weak decoupling method to decompose the coupled output energy and thus match the decoupled demands. Then a matrix optimization model integrated with energy input, conversion, storage and output is introduced as well. Finally, a case study of a combined cooling, heating and power (CCHP) system consisting of a power generation unit (PGU), an absorption chiller, a storage tank and a ground source heat pump (GSHP) is proposed, and three strategies including following electric load, following thermal load and optimized operation strategy are employed to design the optimal nominal capacity configuration. Results show that under the mode so called "electricity feed in tariff" of optimized operation strategy, the optimal nominal capacity of PGU is the largest, and the optimal nominal capacity of GSHP is lower. Meanwhile the system has the optimal integrated performance. Compared with separate system, the integrated performance, annual total cost reduction ratio, carbon dioxide emissions reduction ratio and primary energy saving ratio are 49.99%, 36.33%, 73.54% and 60.11%, respectively.

1. Introduction

Energy is a critical element for human survival and development. The energy structure, which employed fossil fuel as primary resource, has had a significant impact on the development of human society [1]. However, the depletion of conventional fossil fuel has been focused by most researchers; global warming has been altering the modes of energy production, supply and consumption [2]. The energy efficiency of a conventional power plant is approximately 30%, and a large amount of energy is lost during power generation, transmission and distribution [3]. Therefore, as one kind of energy supply mode close to users, combined cooling, heating and power (CCHP) systems have drawn increasing amounts of attention on account of its environmental and social benefits, advantages of effectively utilizing different types of clean energy and reducing energy losses during transmission and distribution [4,5].

A typical CCHP system consists of a power generation system, a waste heat recovery system and an auxiliary system, in which cascade utilization is implemented, the goals of energy saving, environmental protection and economic benefits are achieved [6]. In recent years, due to the rapid development of renewable energy [7], energy diversification and equipment innovations have aggravated further coupling of energy system [8]. Furthermore, some new proposed concepts such as the energy internet, integrated energy systems etc., have constantly

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Nomenclature

V	vectors
H	efficiency matrix
T	diagonal matrix
I	identity matrix
COP	coefficient of performance
R	capital recovery factor
N	installation capacity
C	capital cost per unit
i	interest rate
l	number of equipment
n	service life
F	fuel energy
E	electricity

Symbols

α	distribution coefficient
η	efficiency
k	the site-to-primary energy conversion factors
μ	the emission conversion factors
ω	weight

Subscripts and superscripts

i	input
o	output
k	kth device
pgu	power generation unit
E/e	electricity
Q	heating
R	cooling
S	stored energy
ac	absorption chiller
gshp-r	cooling condition of ground source heat pump
gshp-q	heating condition of ground source heat pump
st-r	cooling condition of storage tank
st-q	heating condition of storage tank
ex	heat exchanger
f	natural gas

Abbreviation

CCHP	combined cooling heating and power
SP	separate system
FEL	following electric load
FTL	following thermal load
FHL	following hybrid thermal-electric load
CDE	carbon dioxide emissions
PEC	primary energy consumption
ICE	internal combustion engine
PGU	power generation unit
GSHP	ground source heat pump
ST	storage tank
ATC	annual total cost
ATCR	annual total cost reduction ratio
CDE	carbon dioxide emissions
CDER	carbon dioxide emissions reduction ratio
PEC	primary energy consumption
PESR	primary energy saving ratio
ESR	energy saving ratio
IP	integrated performance
OC	operation cost
ATC	annual total cost
EFT	electricity feed in tariff

changed the composition of CCHP systems. And the system consists of an energy supply stage (power grid, gas network, district heating, renewable energy), an energy conversion stage (gas turbine, fuel cell, wind turbine, photovoltaics), an energy storage stage (battery, thermal storage apparatus) and an energy consumption stage (electricity, cooling, heating, hot water demands) [9]. As the number of elements in CCHP system increase continuously, the interactions between the stages become more complex, and the physical and mathematical models are continuously expanded. Therefore, comprehensive theoretical modelling and simulation technology consisting all of these stages have become a challenge for the research and development of CCHP system.

In contrast to the separate design, construction and operation of the

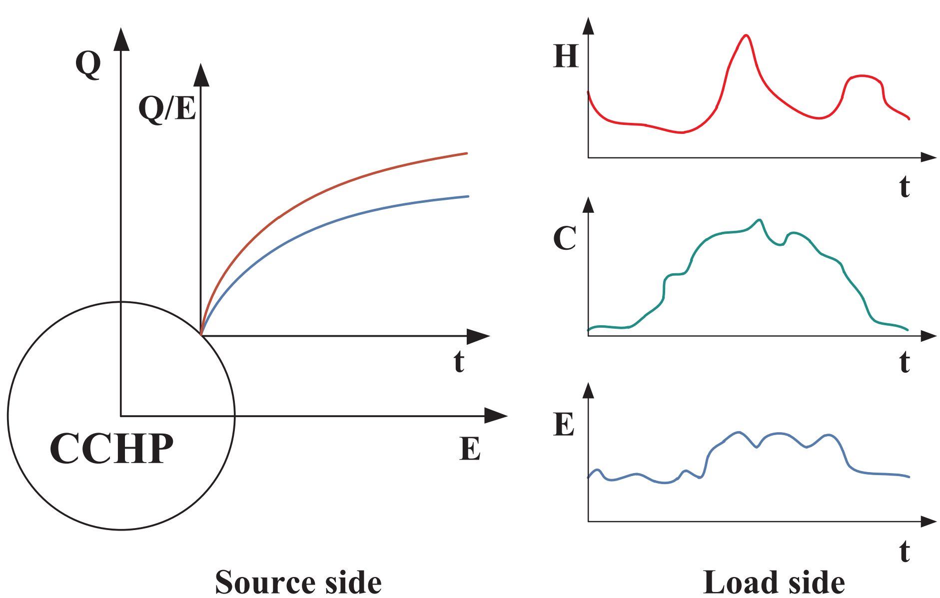

Fig. 1. Necessity of CCHP system decoupling.