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Impacts of feed-in tariff policies on design and performance of CCHP system in different climate zones

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HIGHLIGHTS

- A feed in tariff policy ensuring both energy and economic performance was proposed.
- The proposed policy is the best choice in all climate zones except the hottest zone.
- If improving PER is attractive, FTL is the best choice under the proposed policy.
- The effect of policy improving performance reduces from cold zone to hot zone.

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ABSTRACT

In this paper, a feed-in tariff policy which can contribute to both energy and economic performance of a CCHP system is proposed. By applying this feed-in tariff policy, the impact on design optimization (power generation unit capacity and operation strategy) and system performance (economic, energy, and matching performance) of a hospital CCHP system used in different climate zones are evaluated and analyzed. In policy one (Pol_1), no electricity is allowed to be sold. In policy two (Pol_2), the electricity selling price is constant. In policy three (Pol_3), the selling price of electricity is proportional to the PER (Primary Energy consumption Ratio) of the system when the PER is not lower than a critical value. Otherwise, the selling price is zero. The results show that Pol_3 can ensure both energy and economic performances of CCHP system. The effect of feed-in tariff policy to improve the performance of CCHP system reduces gradually from the cold zone to the hot zone. Multi-criteria decision making results show that Pol_3 with reasonable parameters is the best choice in all climate zones except for the hottest zone in this study. When improving PER is attractive, following thermal load operation strategy is the best choice under Pol_3. In the hottest zone of this study, little excess electricity would be produced and sold to the grid. Feed-in tariff policy has little help to improve the economic and energy performance in this zone.

1. Introduction

Combined cooling, heating, and power (CCHP) systems are becoming more and more popular all over the world because they can help to reduce cost, primary energy, and emission [1]. However, development of CCHP systems is not ideal in many countries because its economic performance is not good enough to attract investment. Various factors would influence the economic performance, such as the supportive policy, the energy prices, the building demands, the initial cost, the electricity market, and the design of CCHP systems. Among them, the supportive policy is one of the most important incentive measures. Economic performance of a CCHP system usually conflicts with its energy performance [2,3], therefore, multi-criteria evaluation has attracted more and more attention [4,5]. As a result, both economic and energy performance should be taken into account when formulating a policy for the generalization of CCHP systems.

During the past decades, various policies and measures have been introduced by different countries to stimulate the development of CCHP system. CHP system support mechanisms of the European countries include tax support, feed-in tariff, certificate scheme, capital grant, and etc. Among them, the most popular mechanism is the feed-in tariff policy. It was used in 16 out of 27 countries [6]. In Germany, several measures have been taken to improve the installation of cogeneration system including duty-free for electricity and gas, subsidy for buying electricity from cogeneration system, and a quota model [1]. In Denmark, feed-in tariff policy not merely helps to improve the share of CHP production, but also incentivizes those systems to operate flexibly [7]. In

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Nomenclature

AC	absorption chiller
ATCSR	annual total cost saving ratio
CCHP	combined cooling, heating and power
COP	coefficient of performance
EC	electric chiller
FEL	following electric load
FTL	following thermal load
HPR	heat to power ratio
ICE	internal combustion engine
Min-PLR	minimum partial load ratio
OEF	on-site energy fraction
OEM	on-site energy matching
OS	operation strategies
PER	primary energy consumption ratio
PGU	power generation unit
SC	stop condition
SHP	separate heat and power
LHV	Low heat value of natural gas (kW h/m^3)

Symbols

C	value of criterion
Cc	initial capital cost coefficient ($/kW)
CM	maintenance cost coefficient ($/kW h)
Cp	capacity (kW)
E	electricity energy (kW)
F	fuel (m^3)
f	partial load factor
I	interest rate (%)
K	proportionality coefficient
n	number
p	price ($/kW h or $/m^3)
Pol	policy
pro	project
Q	thermal energy (kW)
R	capital recovery factor
w	weighting factor
η	efficiency level

Subscripts

ac	absorption chiller
b	boiler
c	cooling
d	distance
e	electricity
ec	electric chiller
eq	equipment
f	fuel
grid	electricity grid
h	heating
HX	heat exchanger
in	into
life	life
out	out
rate	rate
rh	recovery heat for heating
th	thermal
waste	waste
water	water

Superscripts

ben	benchmark
ideal	ideal
non-ideal	non-ideal
nom	nominal
normal	normal

2007, all the cogenerators above 5 MW were forced to operate under spot market conditions [8]. In United States, some specific incentive programs for CHP system have been initiated by states such as California, New York, Massachusetts, and etc [9]. Feed-in tariff policy has been initiated in California. The Federal Energy Regulatory Commission did not preempt this policy, but they approved that the environment externalities, adders for transmission constraints, and multi-tiered rates had been considered by the design of this policy [9]. In Japan, the government promoted the development and installation of CCHP systems through special taxation scheme, investment subsidies and low interest Loans [10]. The total generation capacity of CCHP systems in Japan has increased from 200 kW in 1986 to 9440 MW in March 2010 [11]. Making support policy is one of the most effective ways to promote CCHP system. An appropriate stimulus policy could help to increase the investment and install capacity of CCHP system. Feed-in tariff is one of the most important policies for promoting the installation and development of CCHP systems. It has a great impact on profitability, sizing, and overall energy efficiency of a project. Besides, electricity selling price influences the investment market of CCHP system [12].

Some literatures have researched the influence of the feed-in tariff policy on the design, operation strategy, and economic performance of CCHP systems. Tichi et al. [13] studied the influence of policies for energy price on the design of CCHP systems in Iran. They pointed out that a higher capacity of CCHP system was preferable when selling electricity to the utility was permitted from an economic point of view. They also concluded that the policies of selling electricity and eliminating subsidies could help to widespread the utilization of CCHP systems. Sanaye and Khakpaay [14] compared the design parameters and performance of CCHP system following different scenarios (selling electricity or not) and different operation strategies. The results showed that the relative annual benefit value in no selling electricity scenario was much smaller than that in selling electricity scenario. Siler-Evans et al. [15] evaluated the ability of feed-in tariffs to resist energy price risks. They pointed out that a fixed electricity payment had little effect on risk-resistant, while the energy price risks could be eliminated by a two-part feed-in tariff (one part is for annual capacity, the other part is for the energy which is adjusted with fuel prices). Fragaki [16] studied the conditions for aggregation of CHP plants in the UK electricity market. They found that higher electricity prices could make more profit if some of the produced heat were dissipated. Pade et al. [17] analyzed the relationship among policy support mechanisms, operation strategy and ownership arrangements of micro-CHP system. They stated that different support schemes were appropriate for different countries. Vandewalle and D'haeseleer [18] studied how the gas demand was influenced by the implementation of micro-CHP system. They found that the peak of gas demand would be increased by a low feed-in tariff. From the description above, it can be concluded that the pricing and mechanism of feed-in tariff policy will impact the economic and energy performance of CCHP system a lot.

The feed-in tariff policies could probably be classified into two types based on the present studies. The first type is selling electricity is not permitted. In fact, for CCHP system used in the building, selling electricity is not permitted in many countries and regions in the world, such as China and many other developing countries. The