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Economic optimization of a cogeneration system for apartment houses in Korea

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Abstract

A cogeneration system which can be used as a distributed generation source produces electricity and heat energy simultaneously from a single source of fuel. For industrial and domestic applications, where both kinds of energy are required, the cogeneration system can return fossil fuel energy savings up to 30%, and can reduce CO_2 emissions correspondingly as compared with a conventional system. In this study, eight apartments with residential areas in the range of 57200 m^2 to 182760 m^2 were chosen to study how much energy savings can be achieved by adoption of the cogeneration system in those apartments. Based on the energy demand data for heat and electricity, an optimum configuration of the cogeneration system for each apartment was determined by a developed computer program. The economic gain achieved by introducing the cogeneration system in those apartments was estimated and the monitored values compared with the estimated ones. By adoption of the cogeneration system, the natural gas saved was more than 30% and an average economic gain of US$ 3.6 m^{-2}/year in the overall energy cost was obtained.

Keywords: Cogeneration system; Configuration optimization; Energy demand pattern; Apartments

1. Introduction

Global climate change encountered in recent years demands an evolution in the energy conversion technology for fossil fuels, which will remain the projected dominant energy source up to 2030. Smart consumption, generation, and distribution of power from the fossil fuels are all urgently required to curb CO_2 emissions which are projected increase by 55% between 2004 and 2030 unless current energy policy changes [1].

Distributed generation (DG) of electric power, which minimizes the transmission and distribution losses of electricity, can lead to lower rates and more reliable electrical service for end users. In particular, a cogeneration system which can be used as a DG produces electricity and heat energy simultaneously from a single source of fuel [2,3].

For industrial and domestic applications where both electricity and heat are needed, the cogeneration system turns out to be a very effective energy-saving system [4]. In this study, eight apartment houses with residential areas from 57,200 m^2 to 182,760 m^2 were chosen to assess how much energy savings can be achieved by adoption of the cogeneration system in those apartments. For a 2-year period, the data for consumed electricity and natural gas per hour for those apartments were collected to obtain the representative hourly energy demand pattern for each month. Based on this energy demand data, an optimum configuration of the cogeneration system for each apartment was determined by a developed computer program and the economic gain was estimated by introducing the cogeneration system to those apartment houses. After installing the cogeneration systems in those apartments, the economic gain was monitored for one year and compared it with the estimated numbers before installation. By adoption of the cogeneration system to apartments, up to 30% fossil fuel was saved and the economic gain obtained was up to US$ 5.7 m^{-2}/year with an average gain of US$ 3.6 m^{-2}. The estimated economic gain is in good agreement with the monitored value, within 5%.

2. Apartment houses in Korea

Many people live in apartment houses in major cities in Korea, where the population density is over 1000 people km^{-2}. The typical apartment is a 5–30 story building and the

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Nomenclature

C_p	unit cost of purchased power ($/kWh)
$\bar{C}_p$	maximum contract purchased power cost ($/(kW year))
I	initial equipment cost
K	total number of GE/WHB units
L	total number of BO units
M	total number of representative energy demand patterns
N	total number of GE/WHB units
r	annual interest rate
RR	rate of return
T_D	annual operational hours
w_G	power output (MW)
w_P	purchased power (MW)
W_D	power demand (MW)
x	fuel consumption
y	heat output (MW)
Y_D	heat demand (MW)
Z_f	annual fixed cost ($/year)
Z_r	annual variable cost ($/year)

Greek letters

γ	ratio of the annual maintenance cost of the initial equipment cost
ρ	remainder rate of the equipment at the end of expected life
τ	expected life of equipment

Subscripts

A	BO unit
G	GE or GE/WHB unit
l	lth BO unit
n	nth GT/WHB unit

Superscripts

m	mth energy demand pattern

residential area per household is between 50 m^2 and 150 m^2. Table 1 shows the eight apartment houses studied in this work, which were located in various places in Korea. In this table, the number of households in each apartment, the total residential area, and the residential area per household are shown.

Usually, the electricity needed in the apartments is supplied by the electric power company and heat is supplied from the boilers installed inside each apartment. The amount of the consumed electricity and heat for apartment B as monitored in each month is shown in Fig. 1. Fig. 2 shows the energy demand data in which one day was selected to represent the corresponding month for apartment B. These data were obtained from the consumed electricity and heat energy data measured on an hourly basis and the operation data of the boilers for a 2-year period.

3. Cogeneration system for apartment house

3.1. Cogeneration system

Fig. 3 shows a cogeneration system for a gas engine and waste-heat boiler (GE/WHB) unit with the boiler unit considered in this study. In this figure, the abbreviation BO stands for the boiler. The boilers are installed to supply heat to the apartment house when more heat is required than that can be supplied from WHBs. A gas engine is preferred for the apartment's cogeneration system because of its high efficiency, cheap operation and maintenance costs, and the versatile response to the required load condition. The gas engine (MDE Co. Model 3042L1, Germany) used for the cogeneration system has an electrical efficiency of 34.0% and a recovery efficiency of waste heat of 55.8%. The lower heating value of natural gas was taken to be 9540 kcal Nm^{-3}. No chillers were used for the cooling demand: instead, space cooling was achieved by air conditioners. In Fig. 3, the dotted line, the solid line and the dot-dashed line indicate the flows of fuel, electricity, and steam, respectively.

3.2. Performance characteristics of system components

Generally, the performance characteristics of each component in the plant can be approximately represented by the following linear equations [5]:

$$y = ax + b\delta \tag{1}$$

and

$$\underline{X}\delta \le x \le \bar{X}\delta \tag{2}$$

where x is the input variable, y the product, δ the 0–1 integer variable used to express the on/off condition of each component,

Table 1
Apartments studied

Apartment (number of stories)	Total management floor area (m^2)	The number of households	Residential area per household (m^2)	Location
A (15)	83,400	1436	58.1	Daejeon
B (12,15)	170,830	2146	79.6	Daejeon
C (15)	125,190	1080	115.9	Incheon
D (15)	87,210	672	129.8	Busan
E (15)	126,530	1840	68.8	Daegu
F (13,19,20)	77,260	674	114.6	Wonju
G (25)	182,760	1669	109.5	Busan
H (14,15,17)	57,200	565	101.2	Chuncheon