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Benefit Analysis of Emergency Standby System Promoted to Cogeneration System

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Abstract

Benefit analysis of emergency standby system combined with absorption chiller promoted to cogeneration system is introduced. Economic evaluations of such upgraded projects play a major part in the decisions made by investors. Time-of-use rate structure, fuel cost and system constraints are taken into account in the evaluation. Therefore, the problem is formulated as a mixed-integer programming problem. Using two-stage methodology and modified mixed-integer programming technique, a novel algorithm is developed and introduced here to solve the nonlinear optimization problem. The net present value (NPV) method is used to evaluate the annual benefits and years of payback for the cogeneration system. The results indicate that upgrading standby generators to cogeneration systems is profitable and should be encouraged, especially for those utilities with insufficient spinning reserves, and moreover, for those having difficulty constructing new power plants.

Keywords: emergency standby system, cogeneration system, time-of-use rate structure, mixed-integer programming, nonlinear optimization

1. Introduction

A marked increase in the cost of constructing a generation, transmission and distribution system have also resulted in higher demand charges to customers in the past few years. To reduce the system's peak load and therefore reduce the system's idle stand-by capacity, seasonal and time-of-day (or peak-load pricing) rate structures are usually applied by the utilities. This has increased the benefit of peak shaving by using dispersed-storage-and-generation (DSG) systems [1].

When made a part of an energy management system (EMS)[2] or distribution dispatch center (DDC) of a utility system, DSG may provide benefits to utilities by reducing system peak load, improving reliability, and increasing operation efficiency, which implies that the opportunity cost of generation can thus be reduced by the DSG.

Cost reductions or avoided costs result from saving of both capital carrying charges and operation expenses. However, additional capital investment will be required for the DSG, so the benefit obtained by the utility should be shared with participating customers to promote the DSG. Two customer incentives for DSG are that it allows a time-of-use (TOU) rate structure based on the peak-load pricing theory and reduced fuel costs.

Considering the tremendous quantities of waste heat generated in the production of electricity, it is apparent that there is an opportunity to save fuel by a cogeneration system (CGS). CGS can be described as the simultaneous generation of electrical or mechanical power and usable energy by a single energy conversion system [3]. It has long been common here and abroad. Currently, there is renewed interest in CGS because the overall energy efficiencies are claimed to be as high as 70 to 85%.

Reducing the cost of electricity for industrial and commercial users, relieving excessive demand on utilities, and using fuel efficiently are certainly worthwhile goals. However, careful planning in design and operation is necessary to meet these goals. Therefore, in this paper, a novel optimal operation scheme for small cogeneration systems that are upgraded from standby generators is introduced.

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2. Method

Fig. 1 illustrates the structure of a small CGS investigated in this paper. The sample CGS system is upgraded from a 100 kW gas-engine-driven standby generator by adding an absorption refrigerator and other necessary accessories. The hot-water capacity of this absorption refrigerator is 50 RT. The electricity demands of the system are usually supplied from a public electric utility. However, the cogenerator may operate in a parallel manner to optimize the energy supplies of both the electricity and cooling demands for some suitable time period.

In order to optimize the operation procedure, the parameters of the system are obtained by field testing the sample CGS under full and some partial load conditions. On the basis of the data of the field tests, the fuel cost curve of this system can be obtained by the curve-fitting techniques as shown in Fig. 2 by the dotted line when the fuel cost is 7.84 NT$/m^3.

In this system the heat recovered by the absorption chiller is transformed to equivalent power and so is deducted from the power demand of the centrifugal chiller. On the

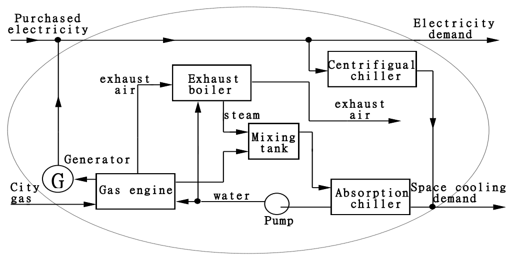


Fig. 1 Structure of a Gas-engine Cogeneration System

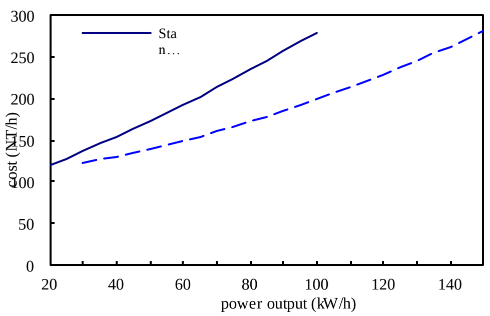


Fig. 2 Fuel-cost Curve of the Sample CGS System

contrary, for the conventional standby generator the only output is electric power. Its power output curve is also shown in Fig. 2 for comparison with that of the CGS.

2.1. Problem Formulation

For customers with a CGS that is upgraded from a standby generator, the total operating cost can be expressed simply as the sum of the payments for electricity to the electric utility and for gas consumption to the gas company. The monthly electricity cost that is the cost function of the optimal operation scheduling of a CGS is proposed as follows:

$$\begin{aligned} f = 30 \times \sum_{i=1}^{24} \{ & PS_i \times OC(P_{Gi}, H_{Gi}) + TP_i \\ & \times [D_i - PS_i \times (P_{Gi} + H_{Gi})] \} \\ & + [R_{CD} \times CD + R_P \times Max(0, D_m - CD)] \end{aligned} \tag{1}$$

Where

i: time interval

PS_i: pseudo switch used to indicate the on/off (1/0) status of CGS during time interval i

$OC(P_{Gi}, H_{Gi})$: operation cost of the CGS during time interval i (NT$/h)

P_{Gi}: output power of the CGS during time interval i (kWh)

H_{Gi}: equivalent power of recovered heat of the CGS during time interval i (kWh)

TPi: TOU rate structure during time interval i (NT$/kWh)

D_i: demand during time interval i (kWh)

R_{CD}: rate when demand is under the contract capacity

R_P: rate if demand exceeds contract capacity

CD: contract capacity

D_m: monthly maximum demand

On the basis of the formulation of the cost function, the optimal operation scheme of the sample CGS and the optimal use of power from the utility can therefore be determined, ultimately, so as to minimize the monthly electricity cost. Control variables of this optimization problem include binary and continuous variables that correspond to the on/off status and the load level of CGS, respectively. Thus, this problem is formulated as a mixed-integer programming problem.

2.2. Optimal Operation Scheme

Using a two-stage methodology and a modified mixed-integer programming technique, a novel algorithm is developed and introduced here to solve the nonlinear optimization problem. In the first stage, the reduction of the capacity charge for power due to the decrease of contract capacity caused by installation of the CGS is not take into consideration. Therefore, at this stage a linear programming algorithm can be applied. However, in the second stage the neglected factor is taken into account and the decomposition and alternative policy method is adopted [4].

The total operating cost of CGS during each time interval can be expressed as:

$$f_i = OC\left(\overline{P_{Gi}}\right) + TP_i \times (D_i - \overline{P_{Gi}}) \quad i = 1,2...24 \tag{2}$$

where $\overline{P_{Gi}}$ is the sum of the electric power and heat output of the CGS. The heat should be converted to its equivalent electric power before the summation can be made. The fuel cost curve shown in Fig. 2 can therefore be formulated as:

$$OC(\overline{P_{Gi}}) = K_1 \times \overline{P_{Gi}}^2 + K_2 \times \overline{P_{Gi}} + K_3 \quad i = 1,2...24 \tag{3}$$

The coefficients K_1, K_2, and K_3 depend on the type, capacity, and maker of the CGS.

Substituting (3) into (2), and then minimizing the obtained equation by linear programming techniques, the optimal operating capacity of the CGS for each time interval can be obtained as follows:

$$P_{GiOM} = (K_2 - TP_i)/(2K_1) \quad i = 1,2...24 \tag{4}$$

From (4), it is clear that fuel cost (K_1,K_2) and TOU rate structure (TP_i) are two important factors in determining the optimal operation capacity.

The constraint of the generator output of the CGS is

$$\overline{P_{Gmin}} \le P_{GiOM} \le \overline{P_{Gmax}} \quad i = 1,2...24 \tag{5}$$

Where

$\overline{P_{Gmin}}$: minimum generator output of the CGS

$\overline{P_{Gmax}}$: maximum generator output of the CGS

The minimum and maximum outputs of the sample CGS are 30 kW/h and 150 kW/h, respectively. The time interval is set to one hour in this paper. The optimal operation benefit during each time interval can therefore be expressed as:

$$Be_{iOM} = TP_i \times P_{GiOM} - OC(P_{GiOM}) \quad i = 1,2...24 \tag{6}$$

Equation (6) shows that the optimal operating benefit is gained from the difference between the savings gained by reducing the electricity charge and the cost of operating the CGS.

The following steps describe the optimal operation scheme in which the benefit gained by the reduction of contracted electricity capacity is considered:

Step 1: Evaluate the optimal operating capacity using (4). In this step, the reduction of the electricity capacity charge due to the decrease of contract capacity made possible by installation of the CGS is neglected.

Step 2: Sort the hourly loads so that they are in descending order, that is

$$D_j \ge D_{j+1} \quad j = 1,2,\dots 23 \tag{7}$$

and record the corresponding hour of each hourly load. The demand differences between maximum hourly load and every hourly load can be calculated as:

$$ED_j = D_1 - D_{j+1} \quad j = 1,2,\dots 23 \tag{8}$$

in which D_1 is the maximum hourly load.

Therefore, if the reduction of the electricity demand charge due to the decrease of contract capacity made possible by installation of the CGS is neglected, the optimal operating capacity of the CGS during each pseudo time period (j) is :

$$\overline{P_{Gj}} = Max(P_{GjOM}, ED_j) \quad j = 1,2,\dots 23 \tag{9}$$

Step 3: The optimal operating benefits for various operating hours are

$$Be_k = \sum_{j=1}^{k} TP_j \times \overline{P_{Gj}} - OC(\overline{P_{Gj}}) + R_{CD} \times ED_k / 30 \qquad k = 1,2,\ldots 24 \tag{10}$$

Step 4: Select the maximum operating benefit from step 3.

$$Be_{max} = Max(Be_k) \qquad k = 1,2,\ldots 24 \tag{11}$$

Therefore, the optimal operation scheme of the CGS for each pseudo time is:

$$\overline{P_{Gj}} = \begin{cases} \overline{P_{Gj}} & j = 1,2,\ldots k \\ 0 & j = k, k+1,\ldots 24 \end{cases} \tag{12}$$

Step 5: Reorder (12) by the actual time order using the record built at step 2. The daily maximum demand can be decreased as:

$$D_{md} = Max(D_i - \overline{P_{Gi}}) \qquad i = 1,2,\ldots 24 \tag{13}$$

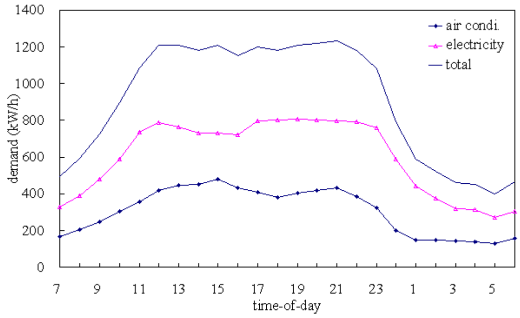
Step 6: Print out the optimal operation schedule, operation benefit, daily maximum demand, and then stop the process.

3. Results and Discussion

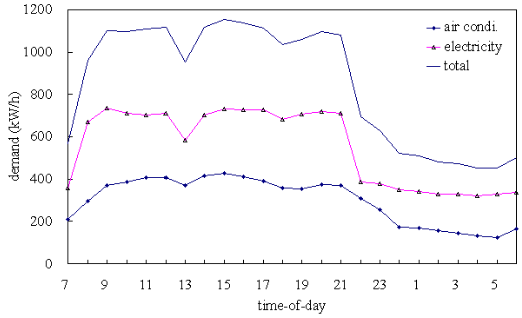
On the basis of the proposed algorithm, a program has been developed. Three sample customers: a hotel, a hospital and an office building are used to demonstrate the proposed algorithm. The sample CGS is assigned to operate six months per year, from June through September in all cases. TOU rates of Taipower are applied for all sample customers. Furthermore, the CGSs of the hotel and hospital are assumed to operate 30 days a month and 24 days for that of the office building.

3.1 The demand pattern of sample customers

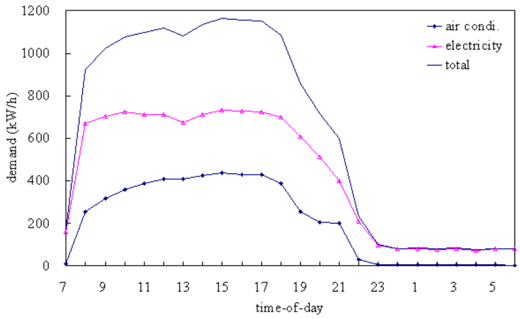
Fig. 3 shows the daily demand patterns for air conditioning, electricity, and total demand of the three sample customers in the summer. Relatively larger hourly demands for electricity occur in the sample hotel in the period between 11:30 and 23:00, and the total demand holds almost constant between 11:00 and 21:00. On the other hand, the total demand of the sample hospital is almost constant between 9:00 and 21:00. There are lunch hours between 12:00 and 14:00. The demands of the sample office building are more concentrated, and result in a lower load factor.



(a) Hotal



(b) Hospital



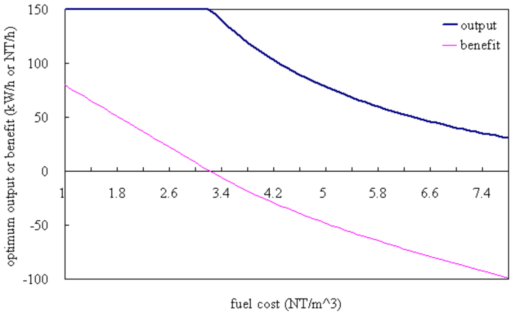
(c) Office building

Fig. 3 Daily Demand Patterns on the Summer

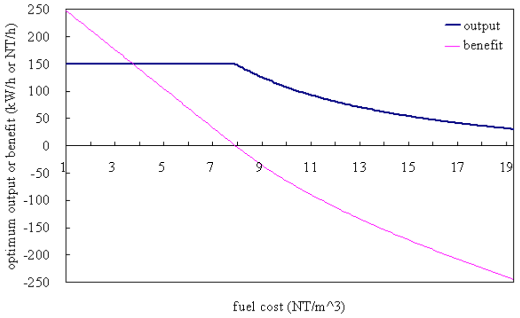
3.2 Optimal Operation Capacity of the Sample CGS

Fig. 4 shows the optimal operation capacity and operation benefit for various fuel costs. For example, Fig. 4-(a) indicates that if the fuel cost is 6.272 NT$/m^3 the optimal operation capacity is 53 kW/h and operation benefit is negative (-72). Therefore, it is not worthwhile to operate the CGS in off-peak periods.

Fig. 4-(b) shows that the operation benefit is positive for peak periods. Hence it is worthwhile to operate the sample CGS when the fuel cost is lower than 8 NT$/m^3. For example, if fuel cost is 6.272 NT$/m^3, the optimal operation capacity is 150 kW/h, that is, the maximum capacity of the sample CGS. In this case the operation benefit is 62 NT$/h.



(a) Off-peak Period (TOU Rate Structure is 0.77 NT$/kWh)



(b) Peak Period (TOU rate structure is 1.89 NT$/kWh)

Fig. 4 Optimal Operation Capacity and Operation Benefit for TOU Rate Structure of Taiwan

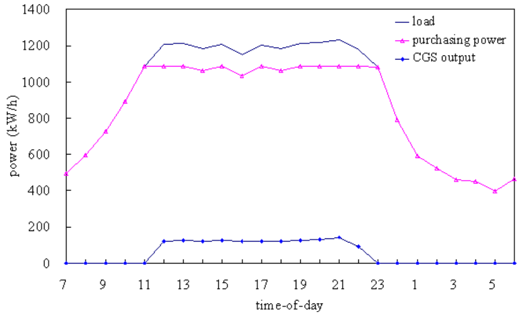
3.3 Optimal Operation Scheme of Sample Customers

Figs. 5 show the optimal operation scheme for fuel costs of 9.408 NT$/m^3. For each hourly load, optimal generating capacity of CGS, and the amount of power being purchased are shown.

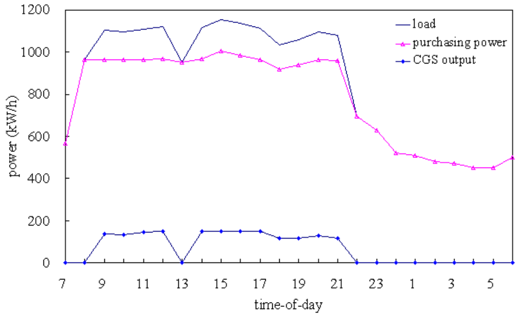
Fig. 5-(a) shows that the maximum daily operation benefit of the sample hotel is produced by operating the CGS eleven hours (from 12:00 to 22:00) per day. The generating capacities at time intervals 14, 15, 17, and 18 are lower than optimal capacity. Hence, the generating capacities of the CGS are set at the optimal capacity, that is, 117.99 kW/h.

3.4 Economic Analysis

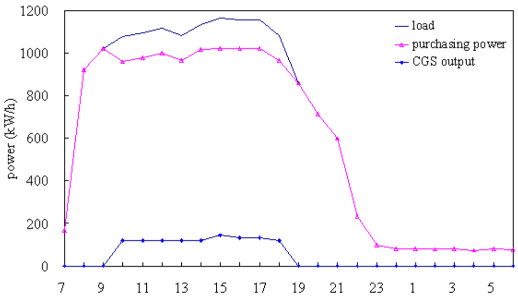
The net present value (NPV) method is used to evaluate the annual benefits and years of payback [5]. Fig. 6 shows the annual benefits of using the CGS for the sample customers at various fuel costs. In general, the more the load coincides in time is, the greater the benefit obtained. The numerical results of the payback analysis for the sample customers are shown in Fig. 7.



(a) Hotel



(b) Hospital



(c) Office Building

Fig. 5 Optimal Operation Scheme at Fuel Cost 9.408 NT$/m^3

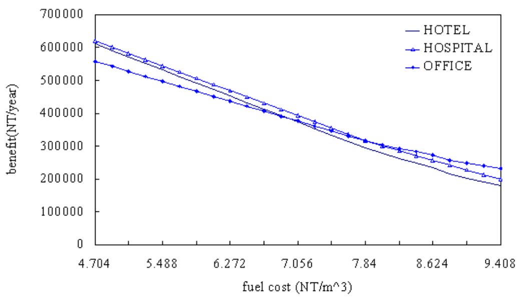


Fig. 6 Annual Benefit

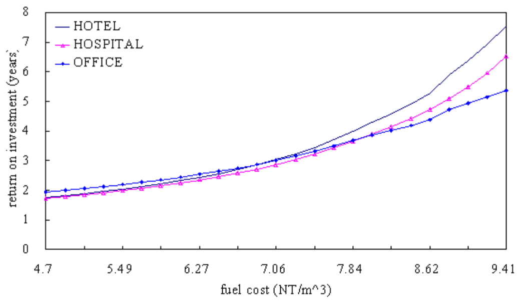


Fig. 7 Return of Investment for Various Fuel Cost

4. Conclusions

A novel optimal operation scheme for small cogeneration systems upgraded from standby generators has been introduced in this paper. On the basis of the proposed algorithm, a program has been developed. Then three sample customers are used to demonstrate the proposed algorithm. The benefits and costs of these sample cases are examined. The fuel cost, time-of-use rate structure and system constraints are taken into account in the evaluation. The results indicate that upgrading standby generators to cogeneration systems is profitable and should be encouraged, especially for those utilities with insufficient spinning reserves, and moreover, for utilities having difficulty constructing new power plants.

Acknowledgement

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