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Techno-Economic Evaluation of Natural Gas-Fired Cogeneration System for a Large Hotel in India

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Abstract

A simple methodology for techno-economic evaluation of a natural gas-fired internal combustion (I.C.) engine based cogeneration system is proposed, and is applied for a large hotel in India as a case study. The capacity of the prospective cogeneration system is estimated on the basis of the electricity requirements of the hotel during the extreme summer/winter season, with and without running the absorption cycle based refrigeration system. The financial analysis reveals a low pay-back period of less than 2 years and a high rate of return of 68.5% that justify the investment in the system. The sensitivity analysis for the net present value (NPV) and the benefit-cost ratio (B/C) indicates that the NPV is sensitive to the values of discount rate and the useful life time while the B/C is sensitive to the capital cost of the system.

Introduction

The hotel industry is one of the several industries that require huge electricity supply from the grid as well as heat energy from fossil fuels such as diesel oil to meet their energy requirements. The energy demand for the hotel persists throughout the year and therefore, any eventual energy peaks and black-outs (common in developing country) may cause huge financial losses to the industry. Before recommending the installation of cogeneration system [1-5] for the hotel, it is therefore necessary to examine its technical and economic viability from the investor's point of view.

A luxury hotel selected for this study is located in New Delhi and has 230 rooms. The cooling of the rooms and the public areas are accomplished using the individual fan coil units and by air handling units (AHU) respectively. The hotel has three centralized air-conditioning refrigeration (ACR) plants; two of these are 350 tonne vapour compression units and one is 250 tonne vapour absorption unit. The steam requirements in laundries (drying, ironing and washing), kitchen, absorption refrigeration plant, and for hot water supply in the rooms are met by two fire-tube type boilers, each of 2 t/h steam generation capacity. The data for monthly electricity consumption is collected from the bills of the electricity company for the year 2001.

In this note a method with simple mathematical formulation is demonstrated with its application for the technical and economical evaluation of a prospective cogeneration system in the studied hotel with respect to its own energy requirements.

Capacity Estimation of Cogeneration System

The monthly heat energy consumption, Q_b can be estimated as:

$$Q_b = \frac{Q_m \ \rho \ (CV) \ \eta_b}{3.6} \tag{1}$$

where Q_m represents the monthly fuel consumption, ρ and (CV) are the specific gravity and calorific value of diesel respectively and η_b is the boiler efficiency.

The heat energy to power ratio for the hotel is found to be less than 0.8 for all the months of the year except for December, January and February. On the basis of low heat energy to power ratio, available cheap natural gas and its eco-friendly nature, the natural gas-fired internal combustion (I.C.) engine based cogeneration system is selected for the hotel. In order to estimate accurately the desired capacity of cogeneration system that can meet all energy requirements throughout the year, it is necessary to have daily-peak electricity and fuel consumption data of the hotel for the whole year. Since the data is not available, it can be approximated with a reasonable accuracy by considering the data for typical days during the extreme winter and summer seasons (Table 1). The capacity of cogeneration system is calculated as:

$$Power \quad of \quad engine = \frac{E_c}{24\eta_g} \tag{2}$$

where, E_c and η_g represent respectively, the electricity consumption on a reference day during the extreme winter/summer season and generator efficiency. The maximum engine capacity of 682 kW_e is found for May 12 (summer season, ACR is not running). The commercially available system of 836 kW_e matching closely to the required capacity of the engine is considered for the present analysis.

Table 1 Energy consumption data of the hotel on typical days during extreme winter and summer seasons

Day	ACR status	Electricity consumption (kWh)	Fuel consumption (Liters)	Boiler operating duration (Hours)
25th Dec. (Winter)	Running	6,900	1,700	18
30th Dec. (Winter)	Not running	7,980	1,250	15
5th May (Summer)	Running	13,500	1,150	14
12th May (Summer)	Not running	14,733	900	11

Techno-Economic Evaluation of Cogeneration System

Estimation of annual monetary benefits (saving) from the proposed cogeneration system

The total cost accrued to the end user on the installation of cogeneration system primarily depends on the cost of electricity/heat produced by cogeneration system as well as the maintenance and operation costs of the system. The monetary value of surplus/deficit electricity (compared to electricity demand of the hotel) generated by cogeneration system for a given month is the sum/difference of the cost of electricity consumed and the cost of surplus /deficit electricity. The cost of surplus/deficit electricity depends on the rate of selling/purchasing of electricity to/from the utility grid by the hotel. It is assumed that the hotel sells the surplus electricity to and purchases the deficit electricity from the grid at @ Rs. 2.0/kWh and Rs.

6.0/kWh (1 US $ = Rs. 48) respectively. However, the financial analysis can be done using the alternate values; the methodology remains the same. It is found that the proposed 836 kW_e cogeneration system generates more heat and electricity than that required by the hotel. The annual monetary value of surplus electricity is calculated from the relation:

$$\text{Annual monetary value of excess electricity } \left(C_{ex.elec.}\right)=\sum_{m=1}^{12}\left(24 d_m E_{in}\eta_s - E_{cm}\right)R \quad (3)$$

where, m=1 to 12 refer to months of the year, d_m the number of days in a month, E_{in} and η_s represent the energy input and electric efficiency of proposed cogeneration system, E_{cm} is the monthly electricity consumption of the hotel before the system installation and R is the selling rate of surplus electricity to the grid. The net annual monetary benefits (NAB) accrued to the investor can be calculated as:

$$NAB = \left[S_t - \left(C_m + C_r \pm C_{ex.elec.}\right)\right] \quad (4)$$

where, S_t represents the annual expenditure incurred to meet total energy requirements before installation of cogeneration system, C_m and C_r are respectively, the annual maintenance and operating costs of the system. $C_{ex.elec.}$ represents the annual cost of surplus/deficit electricity generated by the cogeneration. The positive and negative signs refer to the cost of deficit and surplus electricity respectively. The annual maintenance cost C_m is assumed as a fraction (0.03) of total capital cost of system [5]. The annual operating cost of cogeneration system, C_r is found from the relation:

$$C_r = \frac{86400\, E_{in}\; d_m\; P_f}{(CV)} \quad (5)$$

Financial performance indicators for cogeneration system

The net present value (NPV) of the investment in cogeneration system may be expressed as [6]:

$$NPV = \frac{\left[S_t - \left(C_m + C_r \pm C_{ex.elec.}\right)\right]}{CRF\left(d,t\right)} - C_c \quad (6)$$

where, C_c and $CRF\left(d,t\right)$ represent the capital cost and capital recovery factor of cogeneration system. The simple pay-back period (t_{sp}) for the investment is given as [6]:

$$t_{sp} = \frac{C_c}{\left[S_t - \left(C_m + C_r \pm C_{ex.elec.}\right)\right]} \quad (7)$$

The discounted payback period t_{dp} is obtained by equating NPV to zero and replacing t by t_{dp} in equation (6) and solving the same for t_{dp}. It is given as [6]:

$$t_{dp} = \frac{1}{\ln(1+d)}\left[\ln\left\{S_t - \left(C_m + C_r \pm C_{ex.elec.}\right)\right\} - \ln\left\{S_t - \left(C_m + C_r \pm C_{ex.elec.}\right) - dC_c\right\}\right] \quad (8)$$

The internal rate of return (IRR) on the investment is determined by solving the equation [7]:

$$NAB\left[\frac{(1+IRR)^t - 1}{(IRR)(1+IRR)^t}\right] - C_c = 0 \quad (9)$$

The benefit to cost ratio $\left(B/C\right)$ for cogeneration system can be expressed as [7]:

$$\left(B/C\right) = \frac{\left[S_t - \left(C_m + C_r \pm C_{ex.elec.}\right)\right]}{CRF(d,t)\ \ C_c} \quad (10)$$

Results and Discussion

Some exemplifying calculations are made to determine the numerical values of different financial indicators. The base values of input parameters are: discount rate (d) = 10%; useful life time (t) = 15 years; capital cost (C_c) for 836 kW and 625 kW systems = Rs. $30\text{x}10^6$ and $25\text{x}10^6$ respectively; generator efficiency (η_g) = 90%; energy input (E_{in}) of 836 kW and 625 kW systems = 2154 kW and 1615 kW respectively and price of CNG (P_f) = Rs.13/kg. The low simple and discounted pay-back periods of 18 and 20 months as well as high rate of internal return of 68.5% suggest the financial attractiveness of the investment in cogeneration system. The results are similar to those found in the literature [4]. Figs. 1 and 2 show the results for sensitivity of NPV and B/C. It can be noticed that NPV is sensitive to the values of discount rate and useful life time while B/C is sensitive to capital cost of the system, as expected. The effect of maintenance cost of system on NPV and B/C is negligible.

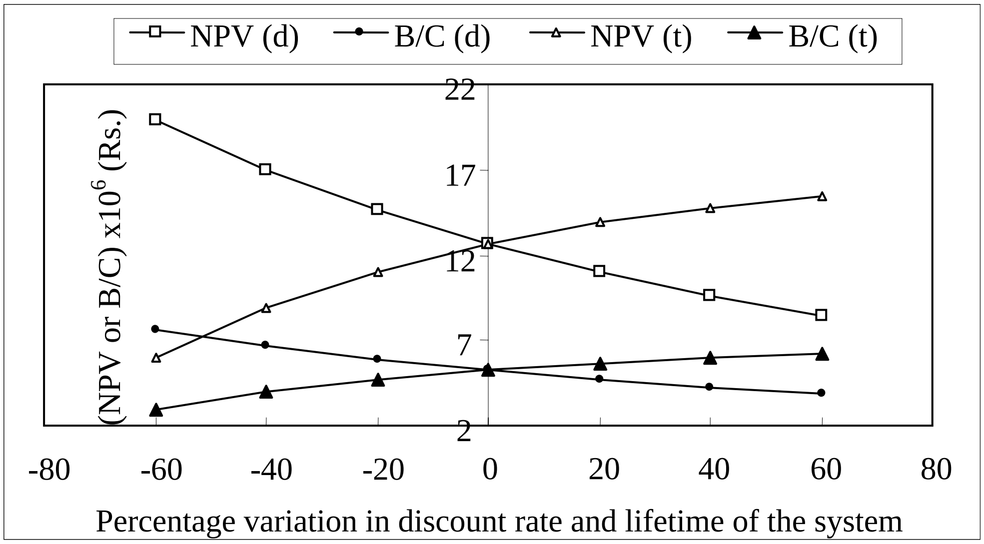

Fig. 1 Sensitivity analysis for NPV and B/C ratio (effect of discount rate and useful life time)

In order to justify the selection of 836 kW_e system, the calculations are repeated for the next lower commercially available 625 kW_e system. Though the 625 kW_e system provides the higher monetary benefits due to lower operational and maintenance costs, but the 836 kW_e system has an added advantage of providing surplus electricity during extreme summer. It also produces more surplus heat than that of 625 kW_e so as to run ACR for the extra hours, resulting in higher monetary benefits.

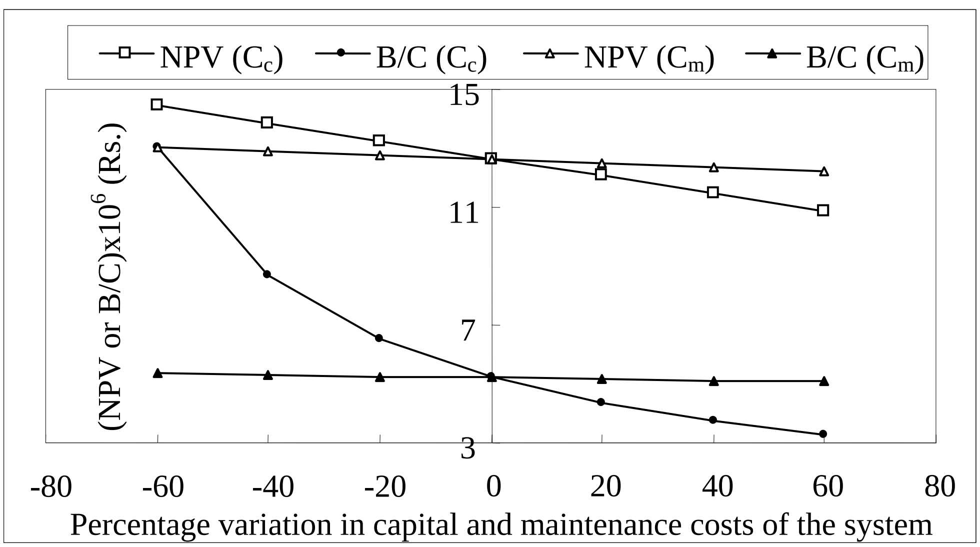

Fig. 2 Sensitivity analysis for NPV and B/C ratio (effect of capital cost and maintenance cost)

Conclusion

The present case study for a large hotel suggests that the proposed 836 kW_e system is technically as well as financially attractive from the viewpoint of an investor. The financial analysis indicates that the system generates annually more electricity (7.32×10^6 kWh) than the requirement (4.90×10^6 kWh), thus resulting in surplus electricity of 2.42 $\times 10^6$ kWh in a year. The annual monetary benefits (savings) accrued due to selling of surplus electricity to a grid is found to be equal to Rs. 4.8 $\times 10^6$ (1 US $ = Rs. 48). Considering repair and operational costs of cogeneration system, the net annual benefit is found to be equal to Rs. 2.05×10^6. Thus, in the prevailing scenario of fuel costs, the system proves to be highly attractive to the investors. The major advantage of the proposed methodology lies in the fact that the mathematical formulation is quite simple, and it can be easily applied with reasonable accuracy and confidence for evaluation and comparison of various commercially available designs of industrial cogeneration systems. Such an analysis would help the prospective users to select a cogeneration system after assessing its technical and economical viability with respect to their own energy requirements.

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