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Assessing and Optimizing the Economy of Distributed Power Generation

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Abstract In the new era of mounting awareness of sustainable development, the distributed power generation is become one of energy system alternatives under consideration. This paper deals with a cost model of distributed power generation. An office building distributed energy system located in Beijing is investigated as a sample of the model. In line with the office building's energy demand profile and the characteristics of Beijing local electric network, an economic feasibility study on the distributed power generation at a competitive electric market structure is presented.

Key words: distributed power generation, cost-effectiveness analysis, model

1. Introduction

The electricity industry, historically a regulated, vertically integrated business with centralized planning and decision making, is now entering a new chapter in which new emerging technologies for distributed power generation, energy storage, controls, communications, and energy management offer the potentiality for customers to manage their energy use and processes on an integration basis. Customers' need for integrated, cost-effective, timely, and reliable solutions opens up significant investment and business opportunities for new products, services, and the emerging technologies will make the future electric system more efficient, reliable, lower cost, decentralized, and smart.

Distributed power generation or distributed generation (DG) for short is currently understood as small power generation units (typically less than 30 MW) strategically located near consumers and load centers that provide benefits to customers and support for the economic operation of the existing power distribution grid,

whether or not those technologies are connected to an electricity grid. Most types of distributed generators utilize traditional power generation paradigms -- reciprocating engines, small combustion turbine, combined cycle turbine, energy storage. But in addition, DG includes fuel cells, micro turbines and renewable power generation methods such as wind, solar, or low-head hydro generation. Distributed power generation can provide a very wide range of benefits depending on the type of generation deployed where it is installed, and when and how it is operated. Distributed power generation can provide spinning reserve, load following, and reactive power. Properly sited and operated distributed power generation can reduce and defer investment in transmission and distribution plant. When operated in a way that reduces line and transformer loading, distributed power generation can reduce losses. Environmental improvements are likely from renewable based distributed power generation as well as from high efficiency gas-fueled sources.

This paper deals with a cost model of distributed

power generation. An office building distributed energy system located in Beijing is investigated as a sample of the model. In line with the office building's energy demand profile and the characteristics of Beijing local electric network, an economic feasibility study on the distributed power generation at a competitive electric market structure is presented.

2. The existing energy supply system of office building

The office building chosen as the sample case located in Beijing and has a total floor area of 5600m². At the moment, the building purchases natural gas for space heating and electricity for lighting, ventilation, air conditioning, water heating, and office equipment. The office building currently relies on an oil-fired diesel engine generation to provide 700kW of backup power for the building's security, fire alarm system and emergency lighting. For purpose heating, ventilating, and air conditioning (HVAC) system the building is equipped with two 350 kW gas-fired boilers and two 630kW electrically driven vapor compression water chillers. The HVAC

Fig.1 Non-Air Condition Power Demand of the Office Building

Fig.3 Monthly Power Demands of Office Building in 1998

Figure 4. Thermal Energy Demand for Space Heating on Representative Day

prime movers provide

the office building with full redundancy, so that the office building can operate with a single boiler and a single chiller.

The office building's energy demands for electricity, space heating, and air conditioning throughout 1998 are shown in figures 1 to 5. Figure 3 shows the average power demand and the 15-minute rolling peak of each month in 1998. Figures 1 shows values of this running average hourly usage throughout a typical day in February 1998 during which no electricity was used for air conditioning. For weekdays, the electric demand profile does not vary significantly from day to day, however, weekend day have its own distinct profiles due to reduced building occupancy.

Since no power was consumed by the office building's electric chillers in February 1998, Figures 1 reflects the office building non-air conditioning (non-a.c.) demand. The non-a.c. load characteristics presented in Table 1 are based on the data shown in these demand curves.

Fig.2 Non-Air Condition Power Demand of Office Building on Weekend Days

Table 1. Characteristics of Office Building's Non-A.C. Power Demand

	weekend day	weekday
Peak load (kW)	1400	2100
average load (kW)	700	1400
base load (kW)	560	590

Figure 5. Hourly Air conditioning Demand of the Office Building

of natural gas is 32809.73kJ/m^3 . The office building consumed a total amount of 12004MW electricity. The capacity cost of the distributed power generation supply energy system is indicated as follows: capital cost of distributed power generation: $4 \times 700 \times 480 = \1344000

O&M cost: $1344000 \times 6\% = \$80640$

Cost of fuel:

$12004000 \times 3600 / 32809.73 / 36\% \times 0.163 = \619363.9 To assess the economy of this distributed power generation supply energy system, discount rate is taken as 11% and the life of the energy supply system is assumed to be 20 years. Assessing result is $\$0.072/\text{kWh}$. The total costs for distributed power generation supplying energy to the office building is: $12004000 \times 0.072 = \864288 ;

It follows that saving made by the distributed power generation supplying energy in comparison with the existing supplying energy system in 1998 is indicated as the following:

$1035321.047 - 864288 = \$171033$,

$171033 / 1035321 \times 100\% = 16.5\%$,

The saving rate is 16.5%.

3. Economic optimization model for distributed power generation energy supply system

Depending on the demand profiles and distributed power generation system, the economic optimization model for distributed power generation energy supply system (DGESS) is formulated and solved by the software called the MATLAB.

The objective of the economic optimization model described here is minimizing the total annual cost, which consists of fixed capacity cost and variable operating cost. The operating cost includes all the purchased energy minus the energy credit from the sale of power to the grid and operation and maintenance expenses.

The yearly requirement is computed based on typical hourly energy demand curve.

$$Z = Z_{vc} + Z_{fc} + Z_{omc} \text{-----}(1)$$

$$Z_{vc} = \sum_{i=1}^r \sum_{j=1}^d \sum_{k=1}^N [(P_{EG} \times (E_{GI} + \Theta N) + P_{EO} \times E_{CG} + P_{fc} \times F_{ch} + P_{fb} \times F_{bl} + \Theta N(N_{last} - N_0) / \varepsilon_{in} \times P_{EGin}] \text{-----}(2)$$

$$Z_{fc} = P_{CH} \times E_{CH} + P_{BL} \times R_{BL} + P_{CC} \times R_{CC} + P_{AC} \times R_{AC} + \Theta_{max} \times p\Theta \text{-----}(3)$$

$$Z_{omc} = (k_{ch} + A_{ch} \times E_{CH} / E_{CHM}) \times P_{CH} \times E_{CH} + (k_{bl} + A_{bl} \times R_{BL} / R_{BLM}) \times P_{BL} \times R_{BL} + (k_{cc} + A_{cc} \times R_{CC} / R_{CCM}) \times P_{CC} \times R_{CC} + (k_{ac} + A_{ac} \times R_{AC} / R_{ACM}) \times P_{AC} \times R_{AC} + (k\Theta + A\Theta \times \phi) \times \Theta_{max} \times p\Theta \text{-----}(4)$$

Notation:

Z_{vc} Variable cost (\$)

Z_{fc} Fixed cost (\$)

Z_{omc} O & M cost (\$)

r The Number of Seasons

d The Number of Typical Days in One Season

N The Number of Periods of One Typical Day

P_{EG} Price of Electricity from Grid (\$/kWh)

E_{GI} Electric Power Consumed from Grid (kW)

ΘN Charge or Release Electric Power in Energy Storage Unit (kW)

P_{EO} Price of Electric from DG (\$/kWh)

E_{CG} Electric Power Supplied to Grid from DG ((kW);

P_{fc} Price of Fuel for DG (\$/m³)

F_{ch} Fuel Consumption by DG(m³)

P_{fb} Price of Fuel for Boiler (\$/m³)

F_{bl} Fuel Consumption by Boiler(m³)

P_{CH} Capacity Cost Coefficient of DG (\$/kW)

E_{CH} Electric Capacity of DG (kW)

P_{BL} Capacity Cost Coefficient of Boiler(\$/kW)

R_{BL} Capacity of Boiler (kW)

P_{CC} Capacity Cost Coefficient of Compression Chiller (\$/kW)

R_{CC} Capacity of Compression Chiller(kW)

P_{AC} Capacity Cost Coefficient of Absorption Chiller (\$/kW)

R_{AC} Capacity of Absorption Chiller (kW)

k_{ch}, A_{ch} Constant to Cover O& M Expenses for DG

k_{bl}, A_{bl} Constant to Cover O& M Expenses for Boiler

k_{cc}, A_{cc} Constant to Cover O& M Expenses for Compression Chiller

k_{ac}, A_{ac} Constant to Cover O& M Expenses for Absorption Chiller

$\Theta N(N_{last} - N_0)$ The Dispersion of Energy in Storage Unit for a Optimize Circle

k_{θ} , A_{θ} Constant to Cover O& M Expenses for Energy Storage Unit

ϕ Rate of Used for Energy Storage Unit

$\Theta_{\max} * p_{\theta}$ Fixed Cost of Energy Storage Unit

The model has been used to optimize the design and daily operation of the energy supply system. The

analysis can be extended to include variation of prices, device efficiency and other elements, along with other demand profiles as well. Figure 7 to 14 show respectively the influences of electricity sales price from DG to grid, price of fuel, efficiency of DG, heat to power rate of DG and optimal capacity and the total operating cost of DG.

Figure 7. Relationship Between Price of Electric from DG to Grid and Optimal Capacity, Annual Total Cost

Figure 9. Relationship Between Efficiency of DG and Optimal Capacity, Annual total Cost

Figure 11. Relationship Between Price of Fuel, Price of Electric from DG to Grid and Annual Total Cost

Figure 8. Relationship Between Price of Fuel and Optimal Capacity, Annual Total Cost

Figure 10. Relationship Between Heat to Power Rate and Optimal Capacity, Annual Total Cost

Figure 12. Relationship Between Price of Fuel, Price of Electric from DG to Grid and Optimal Capacity

Figure 13. Relationship Between Heat to Power Rate, Price of Electric from DG to Grid and Optimal Capacity

Figure 14. Relationship Between Heat to Power Rate, Price of Electric from DG to Grid and Annual Total Cost

4. Conclusions

This paper provides insight into technical and economic aspects of distributed power generation for a office building. It is shown that the feasibility of a distributed power generation energy supply system as the depicted office building, dependences on the local price of electricity and gas and on the system's capital and maintenance cost details. The analysis shows that distributed power generation supply energy for the office building can save total cost about 16.5% compared with existing energy supply system.

The economic optimization model for distributed energy supply system can be used to optimize the behavior of various items of distributed energy supply system. From the result of optimization, we can see that price of electric from DG to grid, price of fuel and efficiency of DG have a strong impact on optimal capacity and total operating cost of DG. In Beijing, the market price range of power from DG to grid is 0.038—0.045€/kW.h. However, the heat to power rate have a exiguous impact on total operating cost of DG, because the heat energy demand of the office building is relatively insignificant.

The electric industry moved from meeting a basic need for electricity to satisfying the multiple objectives of energy efficiency, reliability, customer choice, market competition, fuel diversity, technology choice

and environmental protection. The distributed generation will become a economic and reliable method of applied energy.

5. References

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