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A linear programming approach to the electricity contract capacity problem

Chiung-Yao Chen [a,*], Ching-Jong Liao [b]

[a] Department of Information Management, China University of Technology, 56, Sec. 3, Singlong Road, Taipei 116, Taiwan
[b] Department of Industrial Management, National Taiwan University of Science and Technology, Taiwan

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ABSTRACT

Determination of electricity contract capacity is a problem faced by all industrial customers in Taiwan. In the literature, the problem has been solved using metaheuristics, such as genetic algorithm and particle swarm optimization, which require substantial computation time to solve. In this paper we formulate the problem as a linear program, which requires only polynomial time. Our proposed linear program is better than any metaheuristic approach because a globally optimal solution can be guaranteed while using much less computation time. Two real-world cases, one from a university and the other from a paper mill, are used to demonstrate that the model can minimize the electricity bill for industrial customers.

1. Introduction

Soaring energy prices are making it harder for organizations, even non-profit organizations such as universities, to survive. Electricity comprises an important part of operating costs for many organizations. In Taiwan, all electricity is supplied by the Taiwan Power Company (hereafter referred to as Taipower). Taipower has different electricity tariffs for residential, commercial and industrial customers [1,2]. The service types applicable to industrial customers are further classified into low-tension and high-tension. The rate schedules available for high-tension service are based on time of use (TOU) and maximum demand. This paper focuses on the electricity contract decisions of high-tension industrial customers.

Many larger industrial customers opt to sign a maximum contracted demand contract with Taipower. Such an electricity bill consists of an energy charge and a capacity charge. The energy charge is based on kilowatt hours, while the capacity charge is based on maximum kilowatts consumed (averaged over 15 min) during each TOU period. If the peak demand does not exceed the contract capacity, a fixed capacity charge is levied. On the other hand, if the peak demand exceeds the contract capacity, a penalty charge from two to three times the basic rate is levied. Hence, choosing an excessively low contract capacity will impose high capacity charges, while choosing an excessively high contract capacity may result in an unnecessary basic capacity charge. Therefore, optimal contract capacity decisions have received significant attention from customers with high electricity usage [3,4].

Several metaheuristics, including genetic algorithm and particle swarm optimization, have been proposed for contract capacity problems with different variations [5–7]. However, a careful examination of existing literature reveals that the considered problem has not been proved to be NP-hard. This indicates that the problem can probably be solved in polynomial time. In this paper, we successfully formulate the problem as a polynomial time linear programming (LP) model. The proposed LP model not only can yield a globally optimal solution [8,9], but takes much less computation time than the existing metaheuristics [5] or heuristic search method [6].

* Corresponding author. Tel.: +886 988 152 850; fax: +886 2 2933 6290.
E-mail address: chency@cute.edu.tw (C.-Y. Chen).

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The remainder of this paper is organized as follows. Section 2 provides a detailed description of the Taipower tariff structure and gives a formal definition of the problem. Section 3 proposes two LP models: (1) only peak contract capacity needs to be determined and (2) both peak and off-peak contract capacity need to be determined. Section 4 applies the LP models to two real-world cases, one from a university and the other from a paper mill. Section 5 concludes with some comments and directions for future research.

2. Electricity tariff structure and notation

The structure of Taipower's electricity tariffs [1,2] is designed to recover the total cost of service, subject to government regulation. It takes into account the variable conditions of each customer's demand. The electricity tariffs are different for residential, commercial and industrial customers. The service types applicable to industrial customers are further classified into low-tension and high-tension, according to the customer's contract capacity and service facilities. The rate schedules available for high-tension services are based on TOU and maximum demand. The TOU scheme is separated into peak, medium, and off-peak on a daily and weekly basis, and also into summer (June–September) and non-summer (October–May).

The electricity bill consists of an energy charge and a capacity charge. The energy charge is based on kilowatt hours, with the unit price varying by peak, medium and off-peak. The capacity charge is determined by kilowatts per month based on maximum demand (in 15 minute average) during the TOU period. Since the energy charge is independent from the contract capacity, only the capacity charge needs to be considered in the determination of contract capacity.

Customers taking TOU rate service need to determine a peak period contract capacity. For those who can effectively utilize off-peak electricity, it is also beneficial to determine an off-peak contract capacity. The off-peak period contract capacity is the contract capacity in excess of the peak period contract capacity during the off-peak period. To simplify the problem, we omit two other contract capacities: non-summer and Saturday partial-peak period contract capacities. They are seldom applied to most customers since they are the contract capacities in excess of the peak period contract capacity.

A fixed capacity charge will be levied if the peak demand does not exceed the contract capacity. In addition, there is a surcharge for excess demand: the excess portion within 10% of the contract capacity is charged at twice the rate of the contract capacity, while the portion over 10% of the contract capacity is charged at three times the rate.

For industrial customers with installed facilities and their overall power factor is higher than 80%, incentives are offered to maintain adequate reactive power. For every 1% increase in power factor over 80%, a 0.15% discount rate for the monthly bill will be given. On the contrary, for every 1% of deficient power factor below 80%, a 0.3% surcharge of the total charges will be levied. In case of over contract capacity incident happened in a specific month, no discount will be given for the excess capacity charges.

The following notation is used throughout the paper:

C_{1t}	peak period contract capacity (kW) in month t
C_{2t}	off-peak period contract capacity (kW) in month t
D_t	maximum demand (kW) in month t
D_{1t}	maximum demand (kW) during peak period in month t
D_{2t}	maximum demand (kW) during off-peak period in month t
R_{1t}	rate of peak period contract capacity (NTD/kW) in month t, where NTD stands for New Taiwan Dollar ($R_{1t} = 223.6$ for summer months; $R_{1t} = 166.9$ for non-summer months)
R_{2t}	rate of off-peak period contract capacity (NTD/kW) in month t

3. Linear programming formulation

The objective of this research is to determine the optimal contract capacity for each month so as to minimize the total cost of the electricity bill. The proposed LP formulation consists of four elements: capacity charge, power factor adjustment, expanding construction charge, and disallowed decrease in contract capacities (described below). Two different models are considered.

3.1. Model I

In the fist model, we consider the case where only the peak contract capacity needs to be determined.

3.1.1. Capacity charge

The fixed capacity charge for month t is $R_{1t}C_{1t}$. As stated earlier, excess demand within 10% of the contract capacity is charged at twice the rate of the contract capacity, while excess demand over 10% is charged at three times the rate. Mathematically, the capacity charge, including surcharges, can be expressed as