Application of Linear Programming in Energy Management

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Abstract: ***Now energy and equipment costs increase, efficient energy systems become more important in the overall economics of process plants. in this paper presents a method for modeling and optimizing an industrial steam-condensing system by applying linear programming (LP) techniques. A linear programming method is used to minimize the total costs for energy used net costs in steam condensing systems. The LP method will determine optimum values for the process design variables, so as to achieve minimum cost.***

Keywords: Linear programming, Energy management, optimization

1. Introduction

There is a lot of number of optimization methods are available and these are subject to the very nature of a problem, the level of depth of the analysis. For determination of the optimal solution in problems with several alternative solutions in the linear programming is one of the simplest method. Linear programming was a mathematical model in the Second World War time. It came into being when it turned out that the planning and coordination of projects, and effective use of scarce resources is a necessity. The linear programming issues include optimization linear objective function that should be established a series of limitations in form of linear equality and inequality. Informally, goal of linear programming is using mathematical model to get the excellent output linear (e.g. maximum profit, minimum working).

The standard form of linear programming is
Maximize cTx
Subject to $Ax \leq b$
$x \geq 0$
X stand for a vector of variables and c and b are the vector of coefficients. A is a matrix of coefficients.

Maximized and minimized words are called the objective function. In this case, cTx term b $Ax \leq$ is conditions that show a convex polyhedral and the objective function must be optimized on. Linear programming can be used in various areas of study. Linear programming is specially utilized in commercial and economic situation; however, it can be used in some engineering problems. Most of the industries that used linear programming are transportation, energy, electronics & telecommunications and factories. In addition, it is useful for modeling issues of planning, routing, scheduling, allocation and design. The research of an evaluation of 500 largest companies in the world proved that 85% of them have used linear programming.

2. Applications

Linear programming has lot of applications in military, government, industry and civil engineering In addition, it is mostly used as part of a calculated plan, solving nonlinear programming problem, discrete programming problems, chemicals, optimal control problems and contingency planning. Linear programming is an important optimization for several reasons: A lot of practical problems in operations research can be expressed as a linear programming problem and also a number of other algorithm of optimization problems by linear programming work as sub- problem. Historically, linear programming ideas are inspire many basic concepts of optimization theory such as duality, decomposition and importance of convexity and its generalizations.

3. Electricity tariff structure and notation

The electricity bill depends on an energy charge and a capacity charge. The energy charge is based on kilowatt hours, with the per unit price varying by peak, medium and off peak. We determined per month the capacity charge by kilowatts based on maximum demand (in 15 minute average) during the TOU period. Since the energy charge is not dependent on the contract capacity, only the capacity charge needs to be considered in the determination of contract capacity. Customers taking TOU rate service need got to confirm peak period contract capacity. For those who can effectively utilize off-peak electricity, it is also additionally helpful to determine an off-peak contract capacity. The off-peak period contract capacity is the contract capacity in far more than the peak period contract capacity during the off-peak period. To simplify the matter, we omit two other contract capacities: non-summer and Saturday partial-peak period contract capacities. They are rarely applied to most customers since they are the contract capacities in excess of the peak period contract capacity. A fixed capacity charge is levied if the peak demand doesn't exceed the contract capacity. In addition, there's a surcharge for excess demand the excess portion within 10% of the contract capacity is charged at double 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 put in facilities and their overall power factor is higher than 80%, incentives are offered to take care of 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:

C1t peak period contract capacity (kW) in month t
C2t off-peak period contract capacity (kW) in month t
Dt maximum demand (kW) in month t
D1t maximum demand (kW) during peak period in month t
D2t maximum demand (kW) during off-peak period in month t
R1t rate of peak period contract capacity (NTD/kW) in month t, where NTD stands for New Taiwan Dollar (R1t = 223.6 for summer months;
R1t = 166.9 for non-summer months)
R2t rate of off-peak period contract capacity (NTD/kW) in month t

4. Linear Programming Formulation

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

4.1. Model I

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

4.1.1. Capacity charge

The fixed capacity charge for month t is R1tC1t. 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

$$\begin{cases} \mathrm{R1tC1t}\ \mathrm{Dt} \ \leq \mathrm{C1t} \\ \mathrm{R1tC1t} + 2\mathrm{R1t}(\mathrm{Dt} - \mathrm{C1t})\ \mathrm{C}_{1t} < \ \mathrm{Dt} \ \leq 1{:}1\mathrm{C1t} \\ \mathrm{R1tC1t} + 2(0.1)\mathrm{R1tC1t} + \ 3\mathrm{R1t}(\mathrm{Dt} - \ 1.1\mathrm{C1t})\ 1.1\mathrm{C1t} \ < \ \mathrm{Dt} \end{cases}$$

This expression can be simplified as
R1tC1t + 2R1t(Dt - C1t)+ 1R1t(Dt – 1.1C1t)
where $(X)^+ = \max(x, 0)$. The above expression is non-linear, but it can be remodeled into the following LP expression by defining two new variables, Xt and Yt
Minimize R1tC1t + 2R1tXt + 1R1tYt
Subject to

Xt + C1t ≥ Dt
Yt + 1.1C1t ≥ Dt ;
Xt , Yt ≥0:

4.1.2. Power factor adjustment

As expressed earlier, monthly bill will be reduced by 0.15% for every 1% of the average monthly power factor above 80%, while it will be enhanced by 0.3% for each 1% below 80%. No discount will be offered for the excess capacity charges. Let PF be the power factor adjustment. as an example, if the power factor is 98%, then PF = (98 - 80) 0.15% = 2.7%. If the power factor is 70%, then PF = (70 - 80) 0.3% = - 3.0%. Incorporating the power factor adjustment, the capacity charge is modified as

(1 – PF)(R1tC1t) + 2R1t(Dt - C1t)+ + 1R1t(Dt – 1.1C1t)+,

4.1.3 Expanding construction fee

Electricity customers may modification their peak contract capacity every month. When customers request an increase in the contract capacity, Taipower charges a so-called expanding construction fee [7]. The expanding construction rate is 1759 NTD/kW for summer months, with a 25% discount for non-summer months. Let Et be the expanding construction rate. Then the expanding construction fee can be expressed as
$\mathrm{Et}(\mathrm{C1,t+1} - \mathrm{C1t})^+$,

Where $\mathrm{Et} = \begin{cases} 1759 \text{ for summer months} \\ 1319.25 \text{ for non } - \text{ summer months} \end{cases}$

Due to the disallowed decrease in contract capacity (discussed below), the above expressions can be simplified as Et(C1,t+1 _ C1t).

4.1.4. Disallowed decrease in contract capacities

Customers may request a decrease in the contract capacity at no cost. However, if customers subsequently request an increase in contract capacity at intervals two years, they have to pay a maintenance fee that will cost them more than staying with the initial contact capacity. For simplicity, we ignore the situation of requesting a decrease in contract capacity since such a situation rarely occurs for almost all customers. This assumption can be simply expressed as
C1,t+1 - C1t 0.
The LP model that minimizes the overall electricity bill subject to the related constraints can be summarized as follows:

Minimize

$$\sum_t (1 - \mathrm{PF})\mathrm{R1tC1t} + 2\mathrm{R1tXt} + \mathrm{R1tYt} + \mathrm{Et}(\mathrm{C1,t+1} - \mathrm{C1t})$$

Subject to

Xt + C1t ≥ Dt for all t,
Yt þ 1:1C1t ≥ Dt for all t,
C1,t+1 ≥ C1t for all t,
Xt , Yt ≥ 0 for all t,

4.2. Model II

For some customers, it is helpful to determine an off-peak period contract capacity additionally to the peak period contract capacity. Thus, in Model II we have a tendency to consider both the peak period and off-peak period contract capacities. Note that a surcharge is incurred when the maximum demand during the off-peak period in a month exceeds the sum of the peak period contract capacity and the off-peak period contract capacity, i.e., D2t > C1t + C2t.

In Model II the capacity charge for the peak period is that the same as in Model I, while the capacity charge for the off-peak period, according to the rate schedules of Taipower, is

$R2t\,(C2t - 0.5C1t)^{+,}\ D2t \le C1t + C2t$
$R2t\,(C2t - 0.5C1t)^{+} + 2R2t(D2t - C1t - C2t - X1t)$,
$C1t + C2t \leq D2t \leq 1.1C1t + 1.1C2t$
$R2t\,(C2t - 0.5C1t) + 2R2t(1.1C1t + 1.1C2t - C1t - C2t - X1t) + 3R2t(D2t - 1.1C1t - 1.1C2t - X1t)$,
$1.1C1t + 1.1C2t < D2t$

The capacity charges for peak and off-peak periods can be simplified as
$R1tC1t + R2t(C2t - 0.5C1t)^{+} + 2R1t(D1t - C1t)^{+} + 2R2t(D2t - C1t - C2t - X1t)^{+} + R1t(D1t - 1.1C1t)^{+} + R2t(D2t - 1.1C1t - 1.1C2t - X1t)^{+}$

Similar to Model I, this expression can be transformed into an LP expression by defining three new variables,W2t, X2t, and Y2t (in addition to X1t and Y1t), as follows:

$W2t = (C2t\ \_\ 0.5C1t)^{+}$,
$X2t = (D2t - C1t - C2t - X1t)^{+}$,
$Y2t = (D2t - 1.1C1t - 1.1C2t - X1t)^{+}$.

The expanding construction fee also applies to the capacity charge for the off-peak period, except that it has an 80% discount, i.e., $Et = 1759 \times 0.20 = 351.8$. Taking into account the power factor adjustment, expanding construction fee, and disallowed decrease in contract capacities, the LP for Model II can be summarized as follows:
Minimize

$$\begin{aligned}\sum_t (1 - \mathrm{PF})\mathrm{R1tC1t} + (1 - \mathrm{PF})\mathrm{R2tW2t} + {} & \mathrm{2R1tX} \\ & + \mathrm{2R2tX2t} + \mathrm{R1tY1t} + \mathrm{R2tY2t} \\ & + \mathrm{E1t(C1,t+1-C1t)} \\ & + \mathrm{E2t(C2,t+1C2t)},\end{aligned}$$

Subject to
$X1t + C1t \geqq D1t$ for all t,
$Y1t + 1.1C1t \geqq D1t$ for all t,
$W2t + 0.5C1t - C2t \geqq 0$ for all t,
$X1t + X2t + C1t + C2t \geqq D2t$ for all t,
$X1t + Y2t + 1.1C1t + 1.1C2t \geqq D2t$ for all t
$C1,t+1 \geqq C1t$ for all t,
$C2,t+1 \geqq C2t$ for all t,
$X1t\ , Y1t\ ,W2t\ , X2t\ , Y2t \geqq 0$ for all t,

5. Conclusions

In this paper we have developed LP models to resolve the contract capacity problem. Because solving by linear programming method, the objective function can be written as a linear equation and limitations are imposed. Compared to the existing approach, which requires thousands of iterations to induce an approximate solution, the LP model can be solved very quickly and directly yields an optimum answer. Moreover, the LP model also identifies the time point when a contract capacity should be modified. The tools for solving LP models, e.g., LINDO and Microsoft Excel, are inexpensive and without delay available. Case 2 demonstrates that customers with high off-peak loads should evaluate whether an off peak contract capacity will reduce their bill. though this analysis deals with minimizing electricity bills based on Taipower tariff, it can be applied to alternative electricity customers in capacity cost decision making

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