An enhanced stochastic algorithm for optimal contract capacity of furniture stores

Chia-Sheng Tu\textsuperscript{a}, Ming-Tang Tsai\textsuperscript{b,*}, Chun-Chieh Huang\textsuperscript{b}, Kuei-Ching Su\textsuperscript{b}

\textsuperscript{a}College of Intelligence Robot, Fuzhou Polytechnic, Fujian, China
\textsuperscript{b}Department of Electrical Engineering, Cheng-Shiu University, Kaohsiung, Taiwan, R.O.C.

*E-mail address: k0217@gcloud.csu.edu.tw

Abstract. This paper integrated the Grey Theory and Particle Swarm Optimization to propose an Enhanced Stochastic Algorithm (ESA) for dealing with the optimal contact capacity of the furniture store. ESA is used to find the minimal total annual electricity bill and simultaneously find the optimal contract capacity under the operational and system’s constraints. The historical demand for a furniture store is first collected in this paper. Grey theory is used to predict the next year demand of every month. Based on the Time-Of-Use (TOU) rates employed by the Taiwan Power Company (TPC), the annual electric bill including basic charge and penalty charge is derived to formulate an objective function. Particle Swarm Optimization (PSO) was adopted to minimize the annual electricity bill and simultaneously find the optimal contract capacity. Practical load consumption data were used to prove the validity of the ESA. Users can able to estimate the contract capacity by themselves and curtail the electricity cost.

Keywords: Contract Capacity, Grey Theory, Particle Swarm Optimization, Time-Of-Use

1. Introduction
The power apparatus in a utility must invest tremendous money to consistently supply sufficient electric energy. The electric energy will immediately be supplied by the generating plants to meet the requirements of consumers. The load demand is widely violated in a power system, it is difficult to precisely predict load demand growth \cite{1-3}. For the users, they need to obtain an economical tariff for curtailing their electricity charge. The appropriated contract capacity must be carefully planned to avoid the penalty charge or overestimated contract \cite{4}. For the utility, contract capacity provides customer load information and render correct development and investment in the future. Customers worrying about electric bill, lead to pay extra money due to overestimate the contract capacity or penalty charge. How to achieve a proper contract amount? Many studies were investigate for specific users. \cite{5} use fuzzy theory to analyse and simulate the peak electricity consumption by using the average temperature and electricity fee structure of each month over the years, and then use the Fuzzy Genetic Algorithm (FGA) to find the best contract capacity value. In \cite{6}, Regression Analysis is used to calculate contract capacity. \cite{7} considered both the planning and dispatch of power scheduling to find the optimal contract capacity. \cite{8} used Evolutionary Programming (EP) to develop a software package for solving the optimal contract capacity of...
industrial users based on two-section and three-section time-of-use (TOU) rate schedule [9]. [10] uses statistical and optimization tools to take advantage of the information obtained from the historical behaviour of the customer to search an appropriate contract capacity of its future needs. [11] proposed linear program to determination of electricity contract capacity while using much less computation time. However, this problem is an important issues both the utility and the customers. It is worth of deeper discussion.

In this paper, the Grey Theory and Particle Swarm Optimization is integrated to propose an Enhanced Stochastic Algorithm (ESA) for solving this problem according to individual load data and the rate structure of Taiwan Power Company (TPC). The historical demand for a furniture store is first collected. Grey theory [12] is used to predict the load demand of every month. Based on the Time-Of-Use (TOU) rates employed by the TPC, the annual electric bill including basic charge and penalty charge is derived to formulate an objective function. Particle Swarm Optimization (PSO) [13] is adopted to minimize the annual electricity bill and simultaneously find the optimal contract capacity. Practical load consumption data were used to prove the validity of the novel search. Users can able to estimate the contract capacity by themselves and curtail the electricity cost.

2. The electricity rate structure
The total electricity bill is the summation of the contract capacity charge, the energy charge, and the penalty charge. The contract capacity charge and penalty charge is basically composed three levels.

1. If the monthly demand is less than or equal to the contract capacity, the customers must pay the bill based on contract capacity. This is called the Demand Charge.
2. If the monthly demand exceeds the contract capacity less than 10% of contract capacity, the exceeding amount will be billed with double Demand Charge Rate.
3. If the monthly demand exceeds the contract capacity over 10% of contract capacity, the exceeding amount will be billed with triple Demand Charge Rate.

In our study, the proposed algorithm is tested on a furniture store. In TOU structure, this furniture store is suitable for two-section rate, which consists only of peak load contract capacity. The objective function of contract capacity can be formulated as follows.

\[
\text{Min. } \sum_{i=1}^{24} TDC_i = \begin{cases} 
A_r X_c & \text{when } P_c \leq X_c \\
A_r X_c + (P_c - X_c) \times 2A_r & \text{when } (P_c - X_c) / X_c \leq 10\% \\
A_r X_c + (0.1 \times X_c) \times 2A_r + (P_c - 1.1 \times X_c) \times 3A_r & \text{when } (P_c - X_c) / X_c \geq 10\%
\end{cases} \tag{2}
\]

\(A_r\) : the charge of contract capacity during the i-th month (NT$/KW).
\(X_c\) : the contract capacity during i-th month (KW)
\(P_c\) : the demand during the i-th month (KW)

The summer-season in the TOU tariff represents the season between June 1 to September 30, and the non-summer-season represents the rest of the year. In our study, the TOU rate of contract for summer-season and non-summer-season is $236.2$ NT$/KW and $173.2$ NT$/KW, respectively.

3. The proposed methodology
The purpose of the optimal contract capacity is to minimize the annual bill of the customers. The grey theory is used to predict the load demand of every month. PSO is adopted to fulfill the optimal contract capacity. The searching procedure is described as follows.
3.1 Grey theory
The Grey Model G(1,1) is developed to the load demand forecast. With historical demand data, a grey differential equation is setup through the data processing and accumulating generation. The procedure of GM(1,1) is describe as follows.

Step 1. In put the initial data

$$x^{(0)} = \{x^{(0)}(1), x(2), x(3), ..., x(i)\}$$

(3)

Step 2. Formulated the GM(1,1) model

Step 3. Calculated the accumulating series data

$$x^{(i)}(k) = \sum_{i=1}^{k} x^{(i)}(i), k = 1, 2, ..., n$$

(4)

Step 4. Set the grey differential equation through the data process and accumulating generation.

$$\frac{dx^{(1)}(k)}{dk} + ax^{(1)}(k) = u$$

(5)

$$a$$ and $$u$$, which are the coefficient value, can be described as matrix $[a, u]^T$. $[a, u]^T$ is obtained by least square method as Eq.(6)

$$[a, u]^T = (B^TB)^{-1}B^TY_N$$

(6)

$$B = \begin{bmatrix}
-\frac{1}{2}(x^{(1)} + x^{(2)}) & 1 \\
-\frac{1}{2}(x^{(2)} + x^{(3)}) & 1 \\
-\frac{1}{2}(x^{(k-1)} + x^{(k)}) & 1
\end{bmatrix}$$

$$M$$

Step 5. Solve the grey differential equation

$$\hat{x}^{(1)}(k) = x^{(0)}(1) - \frac{u}{a} e^{-ak} + \frac{u}{a}$$

(7)

Step 6. The original serial value is calculated by Inverse accumulated generating operation in Eq.(8).

$$\hat{x}^{(0)}(k) = \hat{x}^{(1)}(k) - \hat{x}^{(1)}(k - 1)$$

(8)

Step 7. Used the Q-test and C-test Variance($C_e$) to calculate the residual between the real data and predicting data

$$Qe = \frac{1}{n} \sum_{k=1}^{n} \left| \frac{x^{(0)}(k) - \hat{x}^{(0)}(k)}{x^{(0)}(k)} \right|$$

(9)

$$Ce = \frac{1}{n-1} \sum_{k=1}^{n} [x^{(0)}(k) - \hat{x}^{(0)}(k)]^2$$

(10)

3.2 particle swarm optimization
In a PSO system, Birds (particles) flocking optimizes a certain objective function. Each agent knows its best value so far ($X_{best}$) and its position. This information is analogy of personal experiences of
each agent. Moreover, each agent knows the best value so far in the group ($G_{best}$) among other agents around them have performed. The proposed methodology can be summarized in the following steps.

(a) Set the value of input monthly load demand from GM(1,1).
(b) Randomly initialized 30 particle with feasible contract capacity.
(c) Calculate the value of objective function (annual bill) for each particle.
(d) Compare each particle’s objective value with the $X_{best}$. If the objective value is smaller than $X_{best}$, set the value as the current $X_{best}$.
(e) Determine the best particle associated with minimal $X_{best}$ of all particles, and set the value of this $X_{best}$ as current $G_{best}$.
(f) Update velocity and position vectors according to (11) and (12) for each particle.

$$V_{i,d}^{j+1} = K \left[ V_{i,d}^{j} + c_1 \times rand(0,1) \times (X_{best_{i,d}}^{j} - X_{i,d}^{j}) + c_2 \times rand(0,1) \times (G_{best}^{j} - X_{i,d}^{j}) \right]$$

(11)

$$X_{i,d}^{j+1} = X_{i,d}^{j} + V_{i,d}^{j}$$

(12)

Where,

$$K = \frac{2}{2 - c - \sqrt{c^2 - 4c}}$$

\[ c_1, c_2: \text{acceleration constant, In this paper, } c_1 = c_2 = 2.05 \]

$rand(0,1)$: uniform random value with a range of $[0,1]$

$x_{i,d}^{j}$: dimension $d$ of the position of particle $i$ at iteration $j$

$v_{i,d}^{j}$: dimension $d$ of the velocity of particle $i$ at iteration $j$

$x_{best_{i,d}}^{j}$: dimension $d$ of the own best position of particle $i$ at iteration $j$

$G_{best}^{j}$: dimension $d$ of the best particle in the swarm at iteration $j$

(g) The terminating condition is maximal number of iterations. If the preset target is not yet attained, then go back to Step (d) and repeat operation. In this paper, 20 generations is set to stop condition.

4. Case study

The proposed algorithm was applied to solve the optimal contract capacity. The associated data is adapted from a furniture store. The monthly demand from 2014 to 2017 is shown in Figure 1. The
numerical computations were performed using the Matlab language on an Intel Core i5-34705, 2.90GHZ CPU computer with 8GB RAM.

To evaluate the accuracy for GM(1,1) in forecasting, the Q-test and C-test all used in this paper. Least-Square (LS), GM Verhulst and the GM(1,1) were all developed and compared to check performance. Table 1 is the average accuracy of the various methods. With the same training data, the GM(1,1) shows an overall better performance than LS and GM Verhulst. Figure 2 shows the error curves of monthly in the various methods. From the Figure 2, GM(1,1) is also better accuracy than other methods.

Table 1. The average accuracy of the various methods

| Method          | LS Q-test | GM(1,1) Q-test | GMVerhulst Q-test |
|-----------------|-----------|----------------|------------------|
| one-year average| 0.026     | 0.027          | 0.141            |
|                 | 0.319     | 0.408          | 3.007            |

Figure 2. The error curves of monthly

PSO is used to solve the optimal contract capacity problem of the furniture store. The original contract capacity of furniture store is 49kw. Two cases including with TOU rate and non-TOU rate have been studied based on the proposed algorithm. In our study, the optimal contract capacity is 54kw. Table 2 displays the comparison between with TOU rate and non-TOU rate. PSO approach can lead to significant saving of electricity bill no matter what types of contract are used. It can be obviously seen that the electricity bill can be tremendously curtailed through the calculations of our program.

Table 2. The comparison between with TOU rate and non-TOU rate

|          | Total cost with optimal contract (NT$) | Total cost without optimal contract (NT$) |
|----------|---------------------------------------|------------------------------------------|
| Non-TOU  | 446703.43                             | 448829.23                                |
| TOU      | 491304.08                             | 493429.88                                |

*Original contract capacity=49kw
*Optimal contract capacity=54kw

Figure 3 is the convergent characteristics of the optimal contract capacity and Figure 4 is the convergent characteristics of the annual bill. The convergent generation is about 4-th generation.
5. Conclusions
This paper proposes an ESA to predict the load demand calculate the optimal contract capacity for furniture store. Accurately constructing the monthly demand by grey theory is a very useful tool to predict the monthly demand. PSO calculates the optimal contract capacity of low-voltage power tariffs suitable for furniture stores including two modes: non-TOU and TOU. Field demand data of customers are examined to prove the validity of this software. From the execution, users can view the billing for various contract capacities, and also find the optimal one.

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