Customer Load Profile-based Pricing Strategy of Retailers with Generation Assets in Retail Markets

Ziming Ma[1], Haiwang Zhong[1], Qing Xia[1], Jianxiao Wang[1], Xiaowen Lai[1], Xiaohan Zhang[2], Yang Wang[1]
1. Department of Electrical Engineering, Tsinghua University, Beijing, China, 100084;
2. Beijing TsIntergy Technology Co., Ltd., Beijing, China, 100084
E-mail: qingxia@tsinghua.edu.cn

***Abstract*—The integrated architecture of generation and retail is common in a variety of places around the world. The pricing strategy is extremely important to retailers, which significantly affects their profit. ToU and RTP are lack of individuation and the price signal of average cost per kWh is not straightforward to customers. The contribution of a customer's load profile to a generator's utilization rate should be fully considered in retailers' pricing strategy. Therefore, in this paper, a general method to quantitatively evaluate the contribution of a customer's load profile to a generator's utilization rate is firstly proposed. The system or regional typical load profile is chosen as the benchmark. The pricing strategy of retailers with generation assets in retail market based on load profile is then proposed. The load profile-based pricing can provide incentives to customers to optimize their consumption behaviors so that the utilization rate of the generator and the profit of the retailer will increase. Case study indicates that the proposed pricing strategy is feasible and fair to all the market participants.**

***Index Terms*—pricing strategy, load profile, retailer, generation assets.**

I. Introduction

With the deregulation of the power industries in the world, retail markets have been established in some regions, such as the Great Britain and the Electricity Reliability Council of Texas (ERCOT) in the United States. In these retail competition markets, retailers purchase electricity from the wholesale market and sell it to retail customers. Often, the parent companies of retailers own generation assets. For instance, the parent companies of the Big Six Energy Suppliers [1] in Great Britain all have generation assets. Therefore, the integrated architecture of generation and retail is common.

The pricing strategy is extremely important to retailers, which significantly affects their revenue and profit. In addition, the retail price plays an important role in demand response. An appropriate price signal can incentivize customer behavior to be more grid-friendly, such as peak load shaving and valley load filling.

Research has been conducted regarding the pricing strategy of retailers. Reference [2] analyzes the evolutionary stability of pricing strategies in a retail market by adopting an indirect evolutionary approach. Reference [3] structures electricity purchasing and sales return-risk model of retail electricity providers based on the conditional value at risk (CVaR) theory to support the optimal electricity purchasing and sales strategies making of retail electricity providers. Reference [4] performs preliminary analysis of efficient electricity retail price in competitive markets by using a quantitative method termed Capital Asset Pricing Model (CAPM), which is used for determining the expected return from the invested generators. Reference [5] introduces a new incentive-driven scheme called Minimax which encourages customers to flatten their daily load profiles such that they can reduce their electricity bill and help lowering the aggregate peak load demand. Reference [6] shows that the use of dynamic pricing schemes can exacerbate wholesale price volatility and affect the stability of the grid by shifting demand away from abundant supply.

In the real-world application, there are mainly three pricing strategies and the derivations of them. The three main strategies [7] are fixed rate plan, variable rate plan and indexed plan (market rate). Some other strategies like Time of Use (ToU) and Real Time Pricing (RTP) schemes also have been used to incentivize customers to reduce their peak electricity demand during peak hours [8].

However, ToU and RTP focus on the electricity consumption in a specific time period. The price of a certain period is the same to all the customers even if they have totally different load profiles, which makes it lack of individuation. The price signal of average cost for per kWh is not clear for the customers who prefer a simple, straightforward price.

The retail rate of large industrial customers can be set individually through negotiation between customers and retailers [9] considering the load profile and peak-valley difference of the customer, which provides incentives to the customers to optimize their consumption behaviors. However, it is unrealistic for the retailers to negotiate with residential and medium-and-small-sized commercial/industrial (C&I) customers. Currently, there isn't a general and straightforward method except for the negotiation between customers and retailers for load profile-based pricing. There are not enough incentives for residential and medium-and-small-sized C&I customers for demand response.

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The contribution of a customer's load profile to a generator's utilization rate should be fully considered in the pricing strategy. However, how to evaluate the extent of this contribution hasn't been deeply investigated yet. Therefore, this work tries to shed some light on this problem.

The major contributions of this paper are as follows:

1) A general method to quantitatively evaluate the contribution of a customer's load profile to a generator's utilization rate is proposed. The system or regional typical load profile is chosen as the benchmark.

2) The pricing strategy of retailers with generation assets in retail market based on customer-level load profile is proposed. This pricing strategy is based on the incentive compatible principle, which can incentivize customer behavior to be more grid-friendly.

II. The Impact of Customer Load Profile on The Profit of Retailers

To illustrate the impact of customer load profile on the profit of retailers, a retailer with a generating unit is taken as an example. In the analysis, the generator is equivalent to the retailer. Assume that a customer's original load profile is f_1. If the customer's load profile changes from f_1 to f_2, the part above f_1 is denoted as S_1, the part beneath f_1 is denoted as S_2, as shown in Fig. 1.

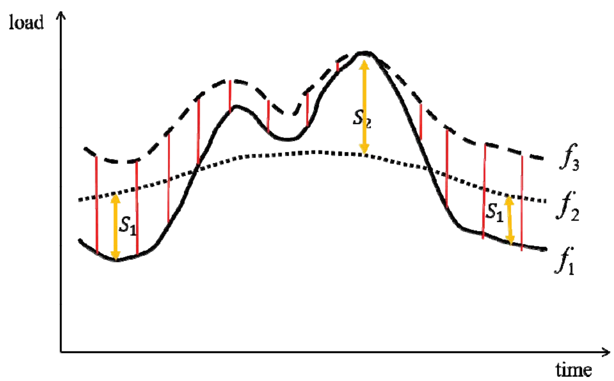

Fig. 1 Customer changes its load profile

A customer's occupation of the power resources is largely determined by its maximum load. The customer's contribution to the power generator by changing its load profile is twofold: 1) to make the generator generates more during off-peak period; and 2) to reduce the peak load so that the power generator can reserve capacity in peak period and serve more customers. Assume that the final load profile is f_3 after the customer changes its load profile and the power generator sells the residual peak capacity to other customers. The benefit of changing load profile should be the difference between the generator's profit of profile f_3 and that of profile f_1, which is shown in Fig. 1. The additional profit is due to the increased utilization of the generator. This part of profit should be shared between the customer and the generator.

III. The Pricing Strategy of Retailers Based on Customer Load Profile

For a given customer load profile, how to quantitatively evaluate its contribution to the utilization rate of power generation equipment? In the previous section, the value of load shifting is discovered by changing the customer's load profile, which leads to a potential idea, the value of a load profile lies in the comparison with other load profiles. Therefore, we need to find a benchmark for judging the value of load profiles. The system or regional typical load profile should be chosen as the benchmark. The typical load profile is the weighted average of the load profiles that belong to the customers. [11] Generators should provide flexibility to follow the typical load profile. Typical load profile has a benchmarking significance to the generators.

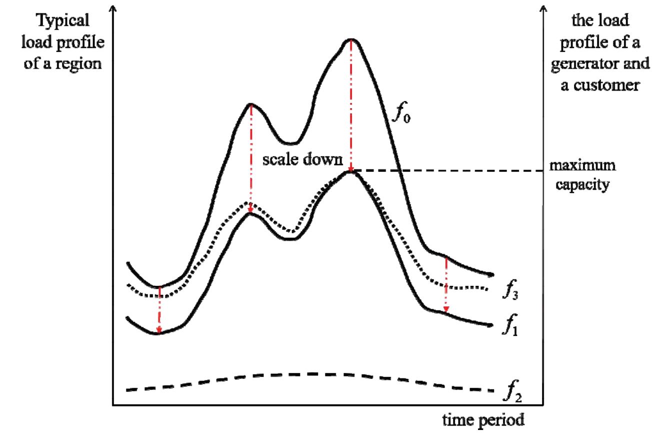

Fig. 2 The typical load profile and the contribution of a customer's load profile to the generator

Assume that the typical load profile of a region is shown as Fig. 2. It is then scaled down proportionally to satisfy the capacity of the generator, which is shown as f_1 in Fig. 2.

Assume that a customer's load profile is shown as f_2 in Fig. 2. The customer's load is much lower than the maximum capacity of the generator. The rest of the capacity is considered to generate in accordance with the typical load profile, which means superposing the typical load profile proportionally on the customer's load profile until the total load profile reaches the generator's maximum capacity. The superposition rule is as follows:

$$f_3(t) = k \cdot f_1(t) + f_2(t) \tag{1}$$

where $P_{\max}$ is the maximum capacity of the generator, $k = \min_t \left\{ \frac{P_{\max} - f_2(t)}{f_1(t)} \right\}$, t is the time period. The superposed profile is shown as f_3 in Fig. 2. The contribution of load profile f_2 to the generator is:

$$F = (\sum_t P_{ft} \cdot \Delta T \cdot \pi - C_f) - (\sum_t P'_{fst} \cdot \Delta T \cdot \pi - C'_{fs}) \tag{2}$$

where P_{ft} is the power of f_3 in period t, ΔT is the duration of each period, π is the original retail price for the typical load profile, P'_{fst} is the power of f_1 in period t. C_f is the total generation cost of f_3, C'_{fs} is the total generation cost of f_1:

$$C_f = \sum_t (a \cdot P_{ft}{}^2 + b \cdot P_{ft} + c) \tag{3}$$

$$C_{fs}{}' = \sum_t (a \cdot P_{fst}{}'^2 + b \cdot P_{fst}{}' + c) \tag{4}$$

where a, b and c are the second-order, first-order and constant coefficients of the quadratic profile of generation cost, respectively.

Based on the incentive compatibility principle, if a customer's contribution to the generator is positive, part of its contribution should be rewarded to the customer. If a customer's contribution to the generator is negative, the customer should be charged with an extra penalty.

However, due to the nonlinearity of the generation cost function, is the profit of the aggregated load profile of all the customers not equal to the sum of all the profit of each customer? Fairness means equal opportunity[10], if the profits are not equal, market participants can benefit from the proposed pricing strategy due to its identity, which makes fairness and feasibility of the proposed pricing strategy questionable.

The original bill of customer i with the original retail price is:

$$R_i = \sum_t f_i^{'}(t) \cdot \Delta T \cdot \pi \tag{5}$$

where $f_i^{'}(t)$ is the load of customer i in period t.

The contribution of customer i to the generator is:

$$\begin{aligned} F_i = &\sum_t f_i(t) \cdot \Delta T \cdot \pi - \sum_t (a \cdot f_i(t)^2 + b \cdot f_i(t) + c) \cdot \Delta T \\ &- \sum_t f_s(t) \cdot \Delta T \cdot \pi + \sum_t (a \cdot f_s(t)^2 + b \cdot f_s(t) + c) \cdot \Delta T \end{aligned} \tag{6}$$

where $f_i(t)$ is the load of superposed profile of customer i in period t, the maximum load of $f_i(t)$ is equal to the maximum capacity of the generator, $f_s(t)$ is the scaled typical load profile to satisfy the capacity of the generator. Assume that the generation enterprise rewards all the positive contribution to the customers and charges the customers all the negative contribution.

The total revenue of the generation enterprise charged from all the customers is:

$$\begin{aligned} F = &\sum_i \sum_t f_i^{'}(t) \cdot \Delta T \cdot \pi \\ &- \sum_i [\sum_t f_i(t) \cdot \Delta T \cdot \pi - \sum_t (a \cdot f_i(t)^2 + b \cdot f_i(t) + c) \cdot \Delta T \\ &- \sum_t f_s(t) \cdot \Delta T \cdot \pi + \sum_t (a \cdot f_s(t)^2 + b \cdot f_s(t) + c) \cdot \Delta T] \\ = &\sum_t f(t) \cdot \Delta T \cdot \pi \\ &- \sum_i [\sum_t f_i(t) \cdot \Delta T \cdot \pi - \sum_t (a \cdot f_i(t)^2 + b \cdot f_i(t) + c) \cdot \Delta T \\ &- \sum_t f_s(t) \cdot \Delta T \cdot \pi + \sum_t (a \cdot f_s(t)^2 + b \cdot f_s(t) + c) \cdot \Delta T] \end{aligned} \tag{7}$$

where $f(t)$ is the load of the aggregated load profile of all the customers in period t.

The total profit of the generation enterprise charged from all the customers is:

$$\begin{aligned} R = &\sum_t f(t) \cdot \Delta T \cdot \pi \\ &- \sum_i [\sum_t f_i(t) \cdot \Delta T \cdot \pi - \sum_t (a \cdot f_i(t)^2 + b \cdot f_i(t) + c) \cdot \Delta T \\ &- \sum_t f_s(t) \cdot \Delta T \cdot \pi + \sum_t (a \cdot f_s(t)^2 + b \cdot f_s(t) + c) \cdot \Delta T] \\ &- \sum_t (a \cdot f(t)^2 + b \cdot f(t) + c) \cdot \Delta T \end{aligned} \tag{8}$$

The deviation between the sum of all the profit of each customer and the profit of the aggregated load profile of all the customers with original retail price is:

$$\begin{aligned} D = &\sum_t f(t) \cdot \Delta T \cdot \pi \\ &- \sum_i [\sum_t f_i(t) \cdot \Delta T \cdot \pi - \sum_t (a \cdot f_i(t)^2 + b \cdot f_i(t) + c) \cdot \Delta T \\ &- \sum_t f_s(t) \cdot \Delta T \cdot \pi + \sum_t (a \cdot f_s(t)^2 + b \cdot f_s(t) + c) \cdot \Delta T] \\ &- \sum_t (a \cdot f(t)^2 + b \cdot f(t) + c) \cdot \Delta T \\ &- \sum_t f(t) \cdot \Delta T \cdot \pi + \sum_t (a \cdot f(t)^2 + b \cdot f(t) + c) \cdot \Delta T \\ = &- \sum_i [\sum_t f_i(t) \cdot \Delta T \cdot \pi - \sum_t (a \cdot f_i(t)^2 + b \cdot f_i(t) + c) \cdot \Delta T \\ &- \sum_t f_s(t) \cdot \Delta T \cdot \pi + \sum_t (a \cdot f_s(t)^2 + b \cdot f_s(t) + c) \cdot \Delta T] \end{aligned} \tag{9}$$

Apparently, the deviation is equal to the sum of the contribution of each customer:

$$\begin{aligned} D = &- \sum_t \sum_i (f_i(t) - f_s(t)) \cdot (\Delta T \cdot \pi - \Delta T \cdot b) \\ &+ a \cdot \Delta T \cdot \sum_t \sum_i (f_i(t)^2 - f_s(t)^2) \end{aligned} \tag{10}$$

Since the typical load profile is the weighted average of the load profiles that belong to the customers, $E(f_i(t)) = f_s(t)$. Therefore,

$$\begin{aligned} E(D) = &- \sum_t \sum_i E(f_i(t) - f_s(t)) \cdot (\Delta T \cdot \pi - \Delta T \cdot b) \\ &+ a \cdot \Delta T \cdot \sum_t \sum_i E(f_i(t)^2 - f_s(t)^2) \\ = &\ a \cdot \Delta T \cdot n \cdot \sum_t \sigma_t^2 \end{aligned} \tag{11}$$

where n is the total number of customers, σ_t^2 is the variance of the superposed profile of all the customers in period t.

In general, the generation cost function is approximately linear, which means the second-order coefficient a is often quite small. The customers of the same class in the same region tend to have similar consumption preference, the value of σ_t^2 will be small. Therefore, $E(D)$ is quite small.

If the benchmark is not the typical load profile, $E(f_i(t))$ is not equal to $f_s(t)$, which makes $E(D)$ much larger.

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The system typical load profile is the aggregation of all the typical load demand of consumers. Based on certain criteria, the consumers are grouped together in a number of classes. Each class has a representative daily load profile which is the weighted average of the profiles that belong to the cluster. [11] If the generation enterprise uses the system typical load profile as the benchmark without distinguishing among different classes, $E(f_i(t))$ may be not equal to $f_s(t)$ when most of its customers are from one particular class (which means it's not diversified). σ^2 and $E(D)$ may be quite large in that case. Industrial typical load profile, commercial typical load profile and residential typical load profile should be made based on electricity big data techniques. The retail price of different classes of typical load profiles should be set first and then the actual retail price of each customer can be set based on its class. Further research on the classification method that can effectively reduce σ^2 and $E(D)$ is quite necessary and will be the future work.

IV. Case Study

The actual daily load data of 913 residential customers of a community in a province of China is used in this case study to verify the proposed pricing strategy. The duration of each period is 30 minutes.

The aggregation of load profiles of all the customers is shown in Fig. 3. Assume that the electricity of the community is supplied by a 100MW unit, the coefficients of the quadratic profile of generation cost is as follows:

$$a = 0.01256, b = 17.48, c = 9.9575$$

The unit of the cost is one dollar and the unit of power is kW .

The typical load profile is formed by expanding the aggregation of load profiles of all the customers to satisfy the maximum generation capacity of the generator considering 5% reserve capacity. The typical load profile is shown in Fig. 3. The peak hours are from 16:30 to 20:30.

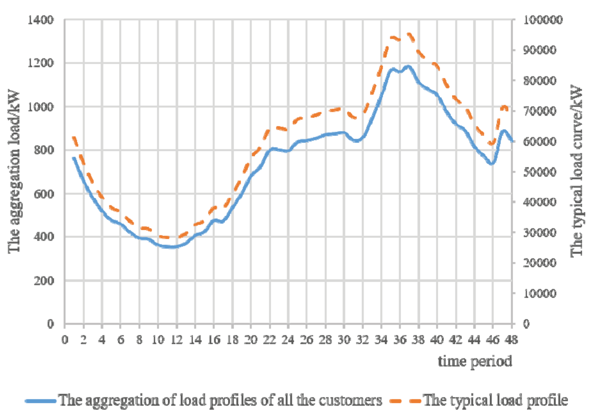

Fig. 3 The aggregation of load profiles and the typical load profile of the community

The original retail price for the typical load profile of the generation enterprise is $\$44 / MWh$. The total bills with original retail price of all the customers in the community is \$1548.6. The maximum ratio of the positive contribution to the original retail bill in the customers is 56.5%, the load profile of the customer is shown in Fig. 4. The maximum positive contribution on that day among the customers is \$4.24, the load profile of the customer is shown in Fig. 4.

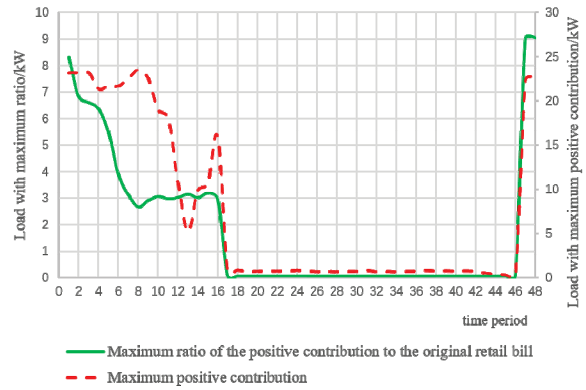

Fig. 4 Load profiles of the customers with positive contribution

The maximum ratio of the negative contribution to the original retail bill in the customers is 324.44%, the load profile of the customer is shown in Fig. 5. The maximum positive contribution on that day among the customers is \$2.10, the load profile of the customer is shown in Fig. 5.

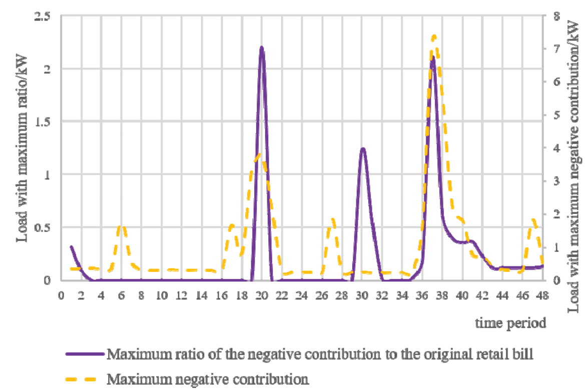

Fig. 5 Load profiles of the customers with negative contribution

As one can observe, the customers with positive contributions mainly consume in off-peak periods and the load in peak periods is quite low. However, the load of the customers with negative contributions is extremely high in peak periods.

The sum of the contribution of all the customers is $\$5\times10^{-4}$, which indicates that the proposed pricing strategy proposed in this paper is feasible and fair to all the market participants..

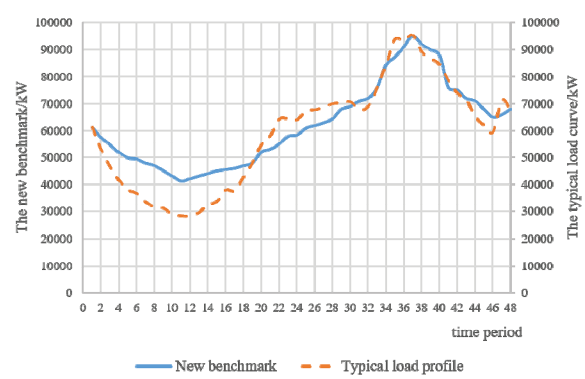

Fig. 6 The comparison between the new benchmark and the typical load profile

However, if other load profiles other than the typical load profile is chosen as the benchmark, which is shown in Fig. 6, the sum of the contribution of all the customers is no longer close to 0, but turns out to be -$24.7. This indicates that it is appropriate to select the system or regional typical load profile as the benchmark.

V. DISCUSSIONS

The pricing strategy gives a general and simple pricing rule for load profiles, which greatly reduces the transaction cost and completely removes the barrier of the personalized pricing of medium-and-small-sized customers. It is easy to form a new business model based on the pricing strategy. With the promotion of smart meters, the customers can easily get their load profiles. Customers can enter their load profiles on the retailer's website and the expected retail price can be calculated and show up immediately.

The consumption preferences of the customers can be evaluated based on the pricing strategy. The electricity bills are settled with ex-post price based on the actual load profiles of customers, which encourages customers to optimize their behaviors. The proposed pricing strategy can help increase the utilization rate of the generator and the profit of the retailer, reduce the difference between peak load and off-peak load, defer the generation expansion and promote the accommodation of renewable energy.

The competition between the power generation enterprises lies in the competition of the original retail price for typical load profile and the coefficients of the quadratic profile of generation cost. The key factors of the competition are the cost except fuel cost and energy-saving technologies of the generators.

The comparison among ToU, RTP and the proposed pricing strategy is shown as TABLE I.

TABLE I
THE COMPARISON AMONG TOU, RTP AND THE PROPOSED PRICING STRATEGY

Items	ToU	RTP	Proposed pricing strategy
Applicable scenarios	Mandatory power pool with uniform hourly price signal	Mandatory power pool with uniform hourly price signal	Retailers with generation assets
Pricing target	Specific time period	Specific time period	The load profile of the customer
Evaluate the consumption behavior	×	×	√
Price fluctuation	Time variant within a day	Time variant within a day	Constant within a day
Clarity	Average cost per kWh is NOT clear to customers	Average cost per kWh is NOT clear to customers	Average cost per kWh is clear to customers
Complexity	Complex	Complex	Simple

VI. CONCLUSION

The customer load profile-based pricing strategy of retailers with generation assets in retail markets is proposed in this paper. A general method to quantitatively evaluate the contribution of a customer's load profile to a generator's utilization rate and profit is proposed. The system or regional typical load profile is chosen as the benchmark to evaluate the contribution of customers' load profile to the generator's utilization rate. Case study indicates that the proposed pricing strategy is feasible and fair to all the market participants. The pricing strategy is easy to form a new business model and encourages customers to optimize their behavior so that the utilization rate of the generator and the profit of the retailer will increase. Hopefully, the proposed pricing strategy will be helpful for the retailers.

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