Real-Time Pricing Strategy by Using the Categority-based Model of Domestic Electric Appliances

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Abstract

Peaking load shaving has great economic and environmental benefits. Compared to the average pricing, the real-time pricing (RTP) can incent the users to shave the peaking load and thus share the benefits of 'flat load curve' between all the participants. In order to get the 'flat load curve', the residential electric appliances are divided into eight categories in terms of self-price elasticities and cross-price elasticities. The price profile is determined one day ahead of real time using the particle swarm optimization (PSO) algorithm. Simulation results show that the load curve tends to be flat under the influence of the optimized price profile.

1 Introduction

Demand Response (DR) has proved to be an effective tool for peaking load shaving. Based on end-use customers' consumption patterns, DR program adopt certain different time-based rates, such as Time of Use (TOU), Critical Peak Pricing (CPP), Extreme Day CPP (ED-CPP), Real-Time Pricing (RTP), to incent the users to shaving the peaking load. It is important to make out a good pricing strategy to promote the DR program. Recently, many publications have introduced the demand side management strategies. An intelligent direct demand side management system, which selects the load(s) to be delayed or reduced based on multi-objective decision making process was proposed by F. Shahnia et al. [1]. In reference [2], an operations planning problem for a price-maker hydro producer has been addressed to find out the optimal combination of price and quantity bids which maximizes total profits in the day-ahead market. An event driven smart home controller enabling consumer economic saving and automated demand side management is proposed by A. Di Giorgio et al. [3]. Jiahai Yuan et al. introduces the multi-agents system simulation, which was provided as an experiment simulation platform for time of use (TOU) price policy decision, to research the price response of large industrial customers [4].

We aim to make a good price profile of RTP, in order to flat the regional domestic electricity load curve. Traditionally demand response (DR) models did not distinguish the different characteristic between domestic loads and not consider the effect of different seasons. Therefore, the previous DR models generally are not very accurate. In order to improve the accuracy of the DR model and make it more reasonable, we divided the domestic electric appliances into eight categories in terms of the self-price elasticity and cross-price elasticity, including refrigerator, dishwasher, washing machine, water-heater, air-conditioner, elastic small loads, electric vehicles and inelastic demand, respectively. By dividing the domestic electric appliances into different categories, forecasting the load curves of each category thanks to smart grid technology, the equivalent self-price elasticity and cross-price elasticity can be adjusted following the variation of the load ratio of each type of domestic appliances in different seasons. Therefore, the DR model of domestic side can be developed more accurately. The customer's satisfaction is taken into account in the pricing strategy model. In this paper, we divided one day into 24 time intervals. 0:00 am to 1:00 am is the first time interval. 1:00 am to 2:00 am is the second time interval, and so on.

In this paper, we analyse both the self-price elasticity and cross-price elasticity of each category of domestic electric appliances, and set reasonable model to evaluate the proposed price profile, and then use PSO to find out an optimized price profile.

2 Problem Formulation

2.1 Nomenclature

$A = \{1,2,3,4,5,6,7,8\}$	A is the electric Appliance type.
$T = \{1,2,3,\ldots,24\}$	T is the time interval set. We divided one day into 24 time intervals.
$E_{a,t}^{0}, a \in A, t \in T$	The original energy demand of a in the time interval t.
$E_{a,t}^{1}, a \in A, t \in T$	Under the influence of optimized price profile, the Total Demand in the time interval t of a.
$E_{a,t}^{in}, a \epsilon A, t \in T$	Under the influence of optimized price profile, The Demand shifted from other time intervals to the time interval t of a.

$E_{a,t}^{out}, a \in A, t \in T$	Under the influence of optimized price profile, The Demand shifted to other time intervals from the time interval *t* of *a*.
$E_{a,t}^{vary}, a \in A, t \in T$	Under the influence of optimized price profile, only considering the self-price elasticities of demand, The varied Demand in the time interval *t* of *a*.
$P_t, t \in T$	The electricity price in the time interval *t*.
$\varepsilon_a, a \in A$	the self-price elasticity of *a*.
$\gamma_a, a \in A$	The cross-price elasticity of *a*.
$BP_t, t \in T$	The benchmark price in the time interval *t*, on which the optimized price profile is based.

2.2 Mathematical Model

The self-price elasticity can be evaluated using Equation(1), where *Quantity* is the quantity of the usage of the good or service and *Price* is the price of this good or service. Δ*Quantity* and Δ*Price* refer to the quantity of usage and price variations respectively, between the periods before and after the implementation of the optimized price profile [5].

For some appliance, the demand is shiftable. The shiftable ratio described by cross-price elasticity and can be evaluated using Equation(2), where $Quantity$ is the same as in Equation(1), $transferQuantity$ refers to the shiftable amount of the total demand.

$$\varepsilon = \frac{\Delta Quantity / Quantity}{\Delta Price / Price} \tag{1}$$

$$\gamma = \frac{transferQuantity}{Quantity} \tag{2}$$

In this paper, according to the difference of their self-price elasticities and cross-price elasticities, we divided the domestic electric appliances into eight categories, they are refrigerator, dishwasher, washing machine, water-heater, air-conditioner, elastic small loads, electric vehicles and inelastic demand, respectively. For example, the elastic small loads are music players, cellphones, PDAs and such low energy consumption appliances. The inelastic demand is the demand of light, television, computer and so on. The same type of domestic appliances should have the same shiftable time domain, the same self-price elasticity and the same cross-price elasticity.

We aim to minimize the difference between peak and valley. In Equation(3), *PtoV* represents the difference between peak and valley of the aggregate load curve under the influence of optimized price profile. So *PtoV* should be minimized.

$$Minimize\ \ PtoV = max_{t\in T}\left(\sum_{a\in A} E_{a,t}^{1}\right) - min_{t\in T}\left(\sum_{a\in A} E_{a,t}^{1}\right) \tag{3}$$

On the other hand, according to the energy conservation, we got the equations of Equation(4), Equation(5), Equation(6) and Equation(7). Equation(6) can be acquired by using Equation(1).

$$E_{a,t}^{in} = \sum_i p_{a,i,t-i} \cdot E_{a,t}^{0} \cdot \gamma_a \,, a \in A, t \in T \tag{4}$$

$$E_{a,t}^{out} = \sum_i p_{a,t,i} \cdot E_{a,t}^{0} \cdot \gamma_a \,, a \in A, t \in T \tag{5}$$

$$E_{a,t}^{vary} = \varepsilon_a \cdot \frac{(BP_t - P_t)}{P_t} \cdot E_{a,t}^{0} \,, a \in A, t \in T \tag{6}$$

$$E_{a,t}^{1} = E_{a,t}^{0} + E_{a,t}^{in} - E_{a,t}^{out} + E_{a,t}^{vary} \,, a \in A, t \in T \tag{7}$$

In Equation(4) and Equation(5), $p_{a,t,k}$ means the weighting factor to shift the shiftable load from the time interval *t* to the time interval *t*+*k* of *a*, under the influence of the optimized price profile. $p_{a,t,k}$is determined by the cross-price elasticity of *a* and the value of *k*. Because the *k* is bigger; the users' satisfaction is lower, for the users should shift their load longer.

Considering that the price of each time interval should not be too low or too high, the price in each time scope should satisfy the constraints of Equation(8) and Equation(9), where the BP_t is the benchmark price in the time interval t, and can be acquired by history data.

To incentive the customers to participate the RTP strategy, the average electricity price for the customers should not be higher than previous average price, so we get the constrains of Equation(10).

$$P_t \geq 0.3 \cdot BP_t \,, t \in T \tag{8}$$

$$P_t \leq 3 \cdot BP_t \,, t \in T \tag{9}$$

$$AvP = \sum_a \sum_t E_{a,t}^{1} \cdot P_t \Big/ \sum_a \sum_t E_{a,t}^{1} \leq Avp_{bp} \tag{10}$$

3 Numerical Results by Using the Particle Swarm Optimization to Optimize the Price

The optimization of the problem in this paper consists on the minimization of a multimodal function with many local minima and a global optimum. It is considered a NP-Hard problem because the computational complexity is high even in simple cases and the computational complexity growing quickly with the growing of the dimension. The PSO is one kind of Swarm Intelligence methods and was used in this kind of NP-Hard problems commonly[6], because its structure is simple and the parameters are easy to adjust[7]. So we choice the PSO algorithm to optimize the price profile, which is varied up and down the benchmark price at certain range.

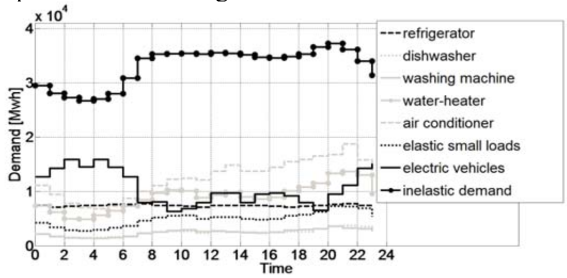

Figure 1 The typical load curves of each type of domestic appliance

We got the typical load curve of eight kinds of the domestic electric appliances by reference [8, 9], as showing in **Figure 1**. The self-price elasticity, cross-price elasticity and shiftable range of each type appliance can also be acquired by survey. We take the history average price of reference [9] as benchmark price, namely BP_t.

We find out a good price profile based on the model proposed in this paper by using the PSO algorithm. Under the optimized price profile, the varied and shifted demand of each time interval is showing in **Figure 2**. In figure 2 we can acquire that the load curve tends to be flat under the influence of the optimized price profile.

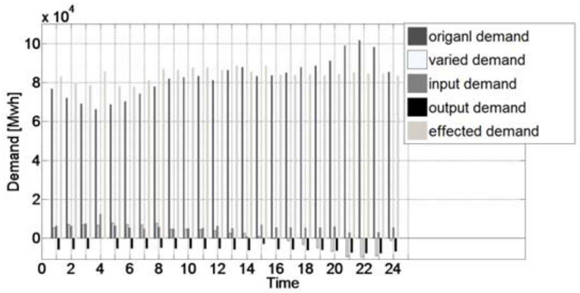

Figure 2 The variated and shifted loads under the category-based model

4 Conclusion

This paper proposes a PSO based methodology to optimize the price profile under the strategy of RTP. We make reasonable DR models by dividing the domestic electric appliances into eight categories according to their characteristics. The same type of domestic appliances have the same self-price elasticity and cross-price elasticity. In the proposed model we also take the customers' satisfaction into consider, when shifting the load. Under the optimized price profile the load curve tends to be more flat.

5 Acknowledgment

This work was supported by the Natural Science Foundation of China under contact (61100159), the Important National Science and Technology Specific Project under contact 2010ZX03006-005-01, Foundation of Chinese Academy of Sciences under contact (KGCX2-EW-104), financial support of the Strategic Priority Research Program of the Chinese Academy of Sciences under contact XDA06020500.

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