A Novel Model of Power Consumption Shifting

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Abstract

The task to creating a sustainable and energy efficient society, which requests users' demand adaptive to energy supply, is attracting more and more attention. However, most of existing shifting model focus on the marginal price of two-level threshold structure, such as BC Hydro. In this paper, we propose a novel model of power consumption shifting with a continuous market price curve, and then present a directly applicable scheme with three-tiered. Users participating in the scheme, however, are motivated to get extra rewards through shifting certain consumption energy from high to low demand time intervals. In addition, taking into account the fact that value ranges of individual shifting costs vary because of different geographic areas, this scheme firstly allocates rewards to power stations in different geographic areas by the way of percentage for shifting cost, and then an appropriate rule is introduced to allocate actual reduction to contributors according their bid. The theoretical properties including individual rationality, budget balance and truthfulness are proven, and show that the proposed scheme is effective and feasible.

Keywords: Renewable energy sources, Consumption Shifting, Mechanism Design, Continuous Market Price Curve

1. Introduction

As technology evolves and electricity demand rises, the task to keep it precisely balanced with supply at all times becomes especially challenging⁽¹⁾. Generally, the Grid has a lot of generators to provide users with power, however, the ever-increasing demands for energy overloads the generators. Therefore, maintaining users' demands curve stability, in particular, can alleviate the risk of disastrous infrastructure collapses, and brings financial and environmental benefits⁽²⁾—as long time overload may damage the generators or some generators can be run on idle, even be shut down

completely. To the best of our knowledge, there is still few work on this issue. In this work, we are motivated to design an applicable consumption shifting scheme to balance the demands for energy.

Nevertheless, there exist many challenges in designing a practical scheme for the issue of power consumption shifting. We list three major challenges are listed as below:

(1) *Budget Balance*: in this paper, we consider that the Grid and users are self-interested. Users hope that the sum rewards are complete allocated for them while the Grid aims to the quota can be completely shifted by users to balance the demands for energy. Therefore, a budget-balanced mechanism is preferred.

(2) *Truthfulness*: Since users are normally rational and selfish, they always tend to strategically manipulate the shifting scheme, if doing so can make them can more rewards. Such behaviours may hurt other users' profit. Hence, designing a shifting scheme which can prevent users from having incentives to lie about their bids is a critical issue.

(3) *Low execution time*: Smart Grid is a very dynamic environment with large amount of users. The power consumption shifting scheme should have a low computation complexity for deciding reduction and rewards allocated to users in order to be feasible in a real scenario.

Our contribution: Based on the problem of balancing the demands for energy, we present a novel model of power consumption shifting. Considering the value ranges of users' shifting cost for energy are diverse due to geographical differences, we introduce the role of Power Station and propose a shifting scheme with three-tiered. What's more, two mechanisms are designed to address the allocation problems: one aims to allocate the reduction(shift) and rewards to Power Stations by the way of percentage for shifting cost, and the other is mainly used to reward users by the way of equalitarianism, meanwhile the above listed challenges are also been solved.

The rest of the paper is organized as follows. In section 2, we introduce the model of power consumption shifting

and our shifting scheme. Section 3 describes our mechanisms and characterize their theoretical properties. We review related works in Section 4. At last, we conclude the paper and discuss our future work in section 5.

2. Model and Shifting Scheme

2.1 System Model

In this section, we present our model for power consumption shifting and formulate a problem about it. All the notations are summarized in Table I.

M_I	The roll-in time-interval(nightly or non-peak hour)
M_O	The roll-out time-interval (daily or peak hour)
εq_τ	the power consumption quantity Grid hope to shift, where $\varepsilon \geq 1$
H	the unit-price of power in M_O
$L(r)$	the unit-price of power in M_I
Q	$Q = \langle Q_1, \dots, Q_j \rangle$ where Q_j is the reduction capacity of PS j
C	$C = \langle C_1, \dots, C_j \rangle$ where C_j is the shifting costs of PS j
q^j	$q^j = \langle q_1^j, \dots, q_i^j \rangle$ where q_i^j is the reduction(shift) capacity reported by user i who chooses PS j
c^j	$c^j = \langle c_1^j, \dots, c_i^j \rangle$ where c_i^j is the shifting costs reported by user i who chooses PS j
R	$R = \langle R_1, \dots, R_j \rangle$ where R_j is the reduction(shift) allocated by Grid for PS j
r^j	$r^j = \langle r_1^j, \dots, r_i^j \rangle$ where r_i^j is the reduction(shift) allocated by PS j for user i
u^j	$u^j = \langle u_1^j, \dots, u_i^j \rangle$ where u_i^j is the reward allocated by PS j for user i
B_j	the set of users who choose PS j , $B_j = \{1, 2, 3 \dots x_j\}$ where x_j is a positive integer.

Table I: Notation

Grid: Grid has a lot of generators to supply users with power (i.e. energy). Grid requests users to shift certain consumption for energy to alleviate the stress on generators in peak hour.

We assume that Grid hopes that users shift εq_τ energy to keep the electricity demand balanced with supply. In our model, we proposed two type of time-intervals M_I, M_O and there exist exactly two different unit-price levels: $H > L(r)$, that characterizes the unit-price of power in M_I are lower. The high demand time-interval with H price are considered to be peak ones, at which demands need to be reduced. The following must then hold: (1) H is constant; (2) $L(r)$ is defined as a continuous unit price curve shown as follows:

$$L(r) = \begin{cases} kr + H & \text{when } r \leq q_\tau \\ k'(r - q_\tau) + L_m & \text{when } r > q_\tau \end{cases} \quad (1)$$

Where q_τ is a threshold, under Grid's estimations, allow for the floor price L_m ($L_m > 0$) to be offered to contributing reducers. (3) $k = \frac{L_m - H}{q_\tau}$, $\frac{k'}{-k} = u$ and $1 \leq u < 2$.

Fig.1: the graph of $L(r)$

Power Station (PS): GS is designated by Grid according to the geographic area. We assume that Grid designates two PSs, namely, $A = \{1, 2\}$. After counting users' bids, PS j will determine the users w_j who can participate in the activity and submit its reduction capacity Q_j and shifting cost C_j to Grid. Obviously, It must be $w_j \subseteq B_j$.

Users: We assume that there are two sets of users (i.e. reducers), denoted by B_1 and B_2 , who have different value ranges of shifting cost and reduction capacity. In this paper, we suppose that users in B_j will choose PS j according their locations. User i will submit its bid to PS, a bid of user i who chooses PS j consists of two parameters: q_i^j and c_i^j .

2.2 An Efficient Power Consumption Shifting Scheme

PS j that participate in the Power Consumption Shifting Scheme (PCSS), is characterized by (a) its reduction capacity Q_j , namely the amount of load that it will curtail (e.g., by shifting), and (b) its shifting cost C_j ($C_j > 0$), that is the cost occurs if consumption of a unit of energy is shifted from M_O to M_I . If PS j shift R_j energy, he will get reward $U_j(R_j, R_{-j}) = (H - L(r_s) - C_j)R_j$ where $r_s = \sum_{j \in A} R_j$.

Fig 2、Consumption of Power is Shifted From M_O to M_I

Given the above, the exact shifting protocol of PCSS with three-tiered can be shown as follows: Every day, Grid announces the forecasted (according to its own information / uncertainly) time-interval M_O and the most preferable time-interval M_I ; Moreover, Grid also designates two PSs according to the geographic area. Then users will choose their corresponding PSs and report their shifting cost and reduction capacity to PS. Next, by counting users' bids, PS will determine the winners and submit its reduction capacity and shifting cost to Grid. In addition, Grid will also adjust and announce the price rates $L(r)$ in M_I and allocate the

actual reduction and the corresponding rewards to PSs. Finally, PS will allocate the actual reduction to users and after users shift the allocated reduction, they will get rewards from PSs.

Fig 3、The shifting protocol of PSCC

2.3 Definition of Concept

To design a practical reduction and rewards allocation mechanism, it should take into account not only financial profit but also economic properties⁽³⁾. Next, we introduce some economic properties we would like to achieve.

Definition 1: (Adjusted Free Disposal) The unit price $L(r)$ in $M_1: R^+ \rightarrow R^+$, is function of r , the consumption quality of energy shifted together, subject to the conditions of adjusted free disposal, i.e.. for $0 \leq r_2 < r_1$, $L(r_2) * r_2 < L(r_1) * r_1$.

Obviously, it is reasonable that the more energy consumed by users, the more bills they should pay for.

Definition 2: (Individual rationality) A mechanism is individual rationality if no users lose by participating in the PSCC. i.e.. the reward allocated to user i satisfied $u_i^j \geq 0$.

This property ensures that users are motivated to participate in the PSCC.

Definition 3: (Truthful Mechanism) A mechanism is truthful when revealing truthful bid is the dominant strategy for each user, i.e. the users are not disadvantaged by telling the truth regardless of other users' bid.

Truthful can ensure the competition in the PSCC is fairness and efficiency, it is essential to avoid market manipulation.

Definition 4: (Double Budget Balance) A mechanism is budget balance if the following hold: ①the total rewards allocated to PSs is equal to the total rewards allocated to users, i.e.. $\sum_{j \in A} U_j = \sum_{j \in A} \sum_{i \in B_j} u_i^j$. ②the total reduction allocated to PS is equal to the total reduction allocated to users, which is also equal to the quantity of energy CRP hope to shift. i.e.. $\sum_{j \in A} R_j = \sum_{j \in A} \sum_{i \in B_j} r_i^j = \varepsilon q_\tau$.

This property ensures that there are no reward and

reduction transfer into or out of system.

The objective of this work is to design a reduction and rewards allocation mechanism for PSCC to keep users' total shifted consumption quality equal to εq_τ so as to keep the demands for power preciously balanced with supply at all times.

3. Reduction and Rewards Allocation Mechanism for PSCC

According the model and Shifting Scheme above, we know that PSCC with three-tiered consists of two power consumption shifting allocation problems (PCSAP): Grid allocates reduction and rewards to PSs, PS allocate reduction and rewards to users. In this section, we present two mechanisms to solve PCSAP, called GP-PCSAP (Grid allocates reduction and rewards to PS for PCSAP) and PU-PCSAP (PS allocate reduction and rewards to users for PCSAP) respectively.

3.1 GP-PCSAP Mechanism

The GP-PCSAP Mechanism is presented in Algorithm 1. The algorithm receives the PS's bid, a vector of reduction capacity and a vector of shifting cost. The output of the GP-PCSAP is the vectors of PS's allocated reduction and the corresponding reward.

In our paper, Grid is reasonable, so it will formulate unit-price $L(r)$ which subjects to adjusted free disposal, the following shows this theorem.

Theorem 1. If CRP formulate $L(r)$ satisfied $L_m \geq \frac{H}{2}$, then $L(r)$ subject to adjusted free disposal.

Proof : Note that $f(r) = r * L(r)$, we know that if $r_1 > r_2 \geq q_\tau$, it must be tenable that $f(r_1) > f(r_2)$. Because

$\lim_{r \rightarrow q_\tau^-} f(r) = \lim_{r \rightarrow q_\tau^+} f(r)$, to prove this theorem, we only need

to consider that $f(r)$ is monotone-increasing function when $r \leq q_\tau$. According the model above, we know that if $r > q_\tau$,

then $f(r) = r * L(r) = kr^2 + Hr$. Since $L_m \geq \frac{H}{2}$, then

$2(H - L_m) \leq H$, and as $k = \frac{L_m - H}{q_\tau}$, we get $q_\tau \leq \frac{-H}{2k}$.

Therefore, it follows that $f(r)$ is monotone-increasing function when $r > q_\tau$. Hence $L(r)$ subject to adjusted free disposal.

From the proof of theorem 1, it follows that the floor price L_m must be at least equal to half of the unit-price H in M_0 .

Theorem 2. PSs will obtain the max total rewards from Grid if setting $\varepsilon = 1$.

Proof: According to the shifting model above, we know that PSs get the total rewards $f(\varepsilon) = \sum_{j \in A} (H - L(\varepsilon q_\tau) - C_j) R_j = (H - L(\varepsilon q_\tau)) \varepsilon q_\tau - \sum_{j \in A} C_j$. As $\varepsilon \geq 1$, then $\varepsilon q_\tau \geq q_\tau$, so $f(\varepsilon) = (H - k'(\varepsilon q_\tau - q_\tau) - L_m) \varepsilon q_\tau - \sum_{j \in A} C_j$. Therefore, when $\varepsilon \geq \frac{1}{2} + \frac{1}{2u}$, $f(\varepsilon)$ is monotone decreasing. However, since $1 \leq u < 2$ and $\varepsilon \geq 1$, then when $\varepsilon = 1$, $f(\varepsilon)$ will obtain the max value. Our claims holds.

The idea of GP-PCSAP is to allocate the reduction by the way of percentage for shifting cost. The procedure about reduction and rewards allocation is as follows.

According the shifting protocol of PCSS above, we know that PS j submits its shifting cost C_j and its reduction capacity Q_j to Grid, then since there are εq_τ energy for Grid that it hope to shift. GP-PCSAP requests Grid allocate $R_j = \varepsilon q_\tau \frac{C_j}{\sum_{j \in A} C_j}$ energy to PS j , and the correspond rewards for PS j is $U_j = (H - L_m - C_j) R_j$. In this paper, we mainly discuss the case that PSs can get the max total rewards from Grid, so from theorem 2, we know ε should equal to 1.

Algorithm 1: GP-PCSAP Mechanism

Input: $Q = \langle Q_1, \dots, Q_j \rangle$; vector of reduction capacity
 $C = \langle C_1, \dots, C_j \rangle$; vector of shifting cost
Output: $R = \langle R_1, \dots, R_j \rangle$: the actual reduction vector;
 $U = \langle U_1, \dots, U_j \rangle$: the reward vector

- 1、 flag $\leftarrow 0$, $M \leftarrow 0$, $\varepsilon \leftarrow 1$
- 2、 **while** flag=0 **do**
- 3、 users report their reduction capacity and shifting cost to PS
- 4、 **for all** $j \in A$ **do**
- 5、 PS j submits its reduction capacity Q_j and shifting cost C_j to Grid
- 6、 CRP adjusts its unit-price rate H and $L(r)$
- 7、 **if** $\sum_{j \in A} Q_j \geq \varepsilon q_\tau$
- 8、 flag $\leftarrow 1$
- 9、 **for all** $j \in A$ **do**
- 10、 $R_j \leftarrow \varepsilon q_\tau \frac{C_j}{\sum_{j \in A} C_j}$
- 11、 **if** $R_j > Q_j$
- 12、 $R_j \leftarrow Q_j$, $M \leftarrow R_j - Q_j$
- 13、 **else**
- 14、 $R_j \leftarrow R_j + M$
- 15、 **for all** $j \in A$ **do**
- 16、 $U_j \leftarrow (H - L_m - C_j) R_j$

17、 Return R and U

3.2 PU-PCSAP Mechanism

The algorithm receives users' bids, which is a vector of reduction capacity and a vector of shifting cost. The output of the allocation mechanism is the vectors of the allocated reduction and the corresponding rewards for users. In addition, PU-PCSAP is a truthful allocation mechanism which ensures every user report their truthful bids (shifting cost and reduction capacity), because users can't get more rewards when they tell a lie.

The idea of PU-PCSAP Mechanism is that PS allocate the reduction and rewards to users by the way of equalitarianism firstly. Next, the procedure of offsetting unsatisfied reduction are executed to address the problem that the reduction allocated to users are beyond their reduction capacity.

Winner determination: From the model above, we know that there exists floor price L_m in M_1 , so PS j will choose user i whose shifting cost c_i^j satisfied $H - L_m - c_i^j \geq 0$. We define the set $w_j \subseteq B_j$ denote the sets of users selected by PS j .

After PS j determine n_j users who participate in the scheme, it will submit its shifting cost and reduction capacity to Grid according the protocol of PSCC, we denote the shifting cost

and reduction capacity it report to PS is $C_j = \frac{\sum_{i \in w_j} (c_i^j)^2}{\sum_{i \in w_j} c_i^j}$ and

$Q_j = \sum_{i \in w_j} r_i^j$ respectively, then user i will get the allocated reduction $r_i^j = \frac{R_j}{n_j}$ and the allocated rewards $u_i^j = \frac{U_j}{n_j}$.

However, there are still a unanswered questions: PS j may assign to user i reduction r_i^j over its reduction capacity q_i^j . We now present an algorithm to solve this problem. In what follows, we explain clearly steps of this algorithm.

To begin, let $d_i^j = q_i^j - r_i^j$ be user i 's (implicitly stated) unsatisfied reduction; that is, the difference between user i 's reduction capacity and the allocated reduction by PS j . We separate the users in w_j into two sets: $w_j^+ = \{i | i \in w_j \text{ and } d_i^j \geq 0\}$, $w_j^- = \{i | i \in w_j \text{ and } d_i^j < 0\}$, according

the algorithm about GP-PCSAP mechanism, we know that PS j 's allocated reduction less than his reduction capacity, that is $R_j \leq Q_j$, therefore, we get the conclusion that $\sum_{i \in w_j^+} r_i^j \geq \sum_{i \in w_j^-} r_i^j$. The algorithm then proceeds as follows.

First, for every PS j , we check the members in w_j^- . If that there is no member, we stop; the problem is inexistent (as all users' reduction capacity can be satisfied with the reduction allocated by PS). If that is not the case, then there exist winners who can't shift the allocated reduction.

The algorithm then sets $D_j := -\sum_{i \in w_j^-} d_i^j$ and ranks the users in w_j^+ by d_i^j in decreasing order. Then, starting from the user with highest d_i^j value, we decrease d_i of the top user until it is equal to the unsatisfied reduction of the $k = i + 1$ user below, so user i will shift extra energy $g_i^j = d_i^j - d_k^j$. Then we do the same for the second top user until its unsatisfied reduction reaches that of the third. We continue this way until all winners' unsatisfied reduction is transferred, that is $D_j = 0$, or one's unsatisfied reduction reaches zero. If the latter happens, we move to the top again and repeat.

Figure 4. The Procedure of Offsetting Unsatisfied Reduction

Algorithm 2: PU-PCSAP Mechanism

Input: $\mathbb{Q} = \langle q^1, \dots, q^j \rangle$: vector for users' reduction capacity vector

$\mathbb{C} = \langle c^1, \dots, c^j \rangle$: vector for users' shifting costs vector

Output: $\mathbb{r} = \langle r^1, \dots, r^j \rangle$: vector for users' allocated reduction vector

$\mathbb{u} = \langle u^1, \dots, u^j \rangle$: vector for users' allocated reward vector

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1、 for all  $j \in A$  do
2、    $w_j \leftarrow \emptyset, n_j \leftarrow 0$ 
3、   for all  $i \in B_j$ 
4、     if  $H - L_m - c_i^j \geq 0$  then
5、        $w_j \leftarrow w_j \cup \{i\}, n_j \leftarrow n_j + 1$ 
6、   for all  $j \in A$  do
7、     for all  $i \in w_j$ 
8、        $r_i^j = \frac{R_j}{x_j}, u_i^j = \frac{U_j}{x_j}$ 
9、   for all  $j \in A$  do
10、     $w_j^+ \leftarrow \emptyset, w_j^- \leftarrow \emptyset$ 
11、     $D_j \leftarrow 0, n \leftarrow 0$ 
12、    for all  $i \in w_j$  do
13、      if  $q_i^j < r_i^j$  then

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14、         $D_j \leftarrow D_j + (r_i^j - q_i^j)$ 
15、      else
16、         $w_j^+ \leftarrow w_j^+ \cup \{i\}$ 
17、       $n \leftarrow n + 1$ 
18、       $d_i^j = q_i^j - r_i^j$ 
19、    end if
20、  end for
21、  if  $D_j \neq 0$ 
22、    Sort  $w_j^+$  in non-increasing order of regret-value
23、     $d_i^j: d_1^j \geq d_2^j \geq \dots \geq d_n^j$ 
24、    repeat
25、      for  $i = 1, 2, \dots, n$  do
26、         $z_i^j \leftarrow d_i^j - d_{i+1}^j$ 
27、        if  $D_j \geq z_i^j$  then
28、           $D_j \leftarrow D_j - z_i^j$ 
29、           $r_i^j \leftarrow r_i^j + z_i^j$ 
30、        else
31、           $r_i^j \leftarrow r_i^j + D_j$ 
32、           $D_j \leftarrow 0$ 
33、        until  $D_j = 0$ 
34、      end if
35、    end for
36、  return  $\mathbb{r}$  and  $\mathbb{u}$ ;

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Proposition 4. The PU-PCSAP Mechanism is individual rationality and truthful for users

Proof: We show that the PU-PCSAP Mechanism is individual rationality and truthful respectively.

individual rationality: According to PU-PCSAP Mechanism, we know that for user $i \in w_j$, while he shift r_i^j resources,

then his reward will be $u_i^j = \frac{U_j}{n_j}$. According to GP-PCSAP

Mechanism, we know $U_j > 0$. Since $n_j > 0$, then $u_i^j > 0$ is tenable. Hence, the PU-PCSAP Mechanism is individual rationality..

Truthful: To prove that the PU-PCSAP Mechanism is truthful, we should consider two case: User may submit mendacious shifting cost or reduction capacity.

For reduction capacity, if user i state mendacious reduction capacity $q_i'^j \neq q_i^j$, it will get rewards $u_i'^j = \frac{U_j}{n_j}$, which does not depend on $q_i'^j$ and his reward does not increase.

Similarity, for shifting cost, if the user i state misleading shifting cost $c_i'^j$, because the idea of PU-PCSAP Mechanism is allocating the reduction and rewards to users by the way of equalitarianism, then the rewards allocated to it is $u_i'^j = \frac{U_j}{n_j}$, and the value does not rely on $c_i'^j$.

As our proposed mechanism maintains that users can not get more rewards by telling the lie, it is proved to be truthful for users' bid.

Proposition 5, The PU-PCSAP Mechanism is double budge balance.

Proof: Firstly, we know that $\sum_{j \in A} R_j = q_\tau$ from the view of GP-PCSAP. To prove this proposition, we assume that if there is no members in w_j^- , user i 's shared reduction capacity and reward is r_i^j and $u_i'^j$ respectively, that is all users can satisfy the reduction allocated by CRP. According the PU-PCSAP Mechanism, we know that reduction and rewards allocated to user i is $r_i'^j = \frac{R_j}{n_j}$ and $u_i^j = \frac{U_j}{n_j}$, so we

get that $\sum_{i \in w_j} r_i'^j = \frac{R_j}{n_j} * n_j = R_j$ and $\sum_{i \in w_j} u_i^j = \frac{U_j}{n_j} * n_j =$

U_j . However, in the GP-PCSAP mechanism, we should consider two type of users: users in w_j^+ and users in w_j^- , and then for reduction, we get that $\sum_{i \in w_j} r_i^j = \sum_{i \in w_j^-} r_i^j +$

$$\sum_{i \in w_j^+} r_i^j = \sum_{i \in w_j^-} q_i^j + \sum_{i \in w_j^+} r_i'^j + \sum_{i \in w_j^-} (r_i'^j - q_i^j) =$$

$$\sum_{i \in w_j^-} r_i'^j = R_j. \text{ Hence, we get that } \sum_{j \in A} \sum_{i \in w_j} r_i^j =$$

$\sum_{j \in A} R_j = q_\tau$ and $\sum_{j \in A} \sum_{i \in w_j} u_i^j = \sum_{j \in A} U_j$. Since there are no reward and reduction transfer out of or into system, then our claim holds

Proposition 6, The Computation Complexity of PSCC is $O(|A||B| \log|N|)$ where $B = \{B_j | |B_j| > |B_k|, j, k \in A\}$.

Proof: In GP-PCSAP mechanism, it runs in $O(|A|)$ for Grid allocates reduction and rewards to PSs. For PU-PCSAP mechanism, PS allocates the reduction and rewards for $|A|$ PSs, so the number of iterations is $|A|$. In each iteration, the major computation is sorting to the list of users according to the unsatisfied reduction, which runs in $O(|B_j| \log|B_j|)$. The procedure of offsetting regret-value in $O(|B|)$ is negligible. Thus, the computational complexity of the proposed shifting scheme with three-tiered is polynomial and corresponds to $O(|A||B| \log|B|)$.

4. Related Work

To the best of our knowledge, there is very little work in practical mechanism design for the model of power consumption shifting with considering the range difference of shifting cost of users in different areas. In the following, we focus on the existing closely related works in this domain and describes their similarities and differences from our work.

Schülke et al.⁽⁴⁾ propose a mechanism, which aims to optimize the power grid by balancing rising and declining consumption demands, to predict and control the energy consumption. They describes the architecture for an energy consumption control platform to flatten the overall power demands in order to avoid cost intensive production peaks. Mohsenian-Rad et al.⁽⁵⁾ and Ibar et al.⁽⁶⁾ propose some approaches with fixed strategies retained for users to optimize consumption schedules by the way of searching for Nash Equilibrium in specific game setting. However, their mechanism does not ensure truthfulness.

Akasiadis and Chalkiadakis⁽⁷⁾ present a directly applicable scheme for electricity consumption shifting which allows even agents with initially forbidding shifting cost to participate in, to promote consumer cooperatives participation, to achieve the effective flattening of the demand curve. Unlike their work, we considered the fact that value ranges of individual shifting costs and capacities vary because of different geographic areas, and introduce the role of Power Station.

Veit et al.⁽⁸⁾ propose a novel multiagent coordination algorithm to shape the energy consumption of the cooperative and present an iterative algorithm in which a virtual price signal is sent by the coordinator to induce consumers to shift demand. This is similar to our work. However, they employ typical market price function (i.e., group price⁽⁹⁻¹¹⁾) where the prices are different in each time slot and has a threshold structure. Unlike their work, we propose a continuous market price curve and investigate some properties about it.

5. Conclusions

In this paper, we proposed a novel model of power consumption shifting and studied the problem of mechanism design for it. Considering users' shifting cost and reduction capacity for power will vary due to geographical differences, we introduce the role of power station and present a directly applicable scheme with three-tiered. Moreover, our

theoretical analysis proves that the proposed mechanism can simultaneously achieve the individual rationality, truthfulness and budget balance. In our future work, we will implement our design and investigated the impact of unit-price function in M_1 for the system. In addition, improving our model of power consumption shifting and the solution quality of the proposed mechanism will be also taken in to consideration.

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