Modeling of Energy Management Systems for Commercial Parks with Thermodynamic Equipment

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Abstract. Commercial park energy management systems (CPEMS) can reasonably plan appliances’ schedule of commercial tenants (CT) and lower their electricity purchasing cost. However, in the existing models, thermodynamic equipment like air conditioners and water heaters are not precise enough, failing to reflect the actual operating characteristics of the equipment. This paper presents an energy management system model including thermodynamic equipment. By coordinating the electricity consumption schedule of multiple CTs, CPEMS can reduce CTs’ electricity purchase costs. In the demonstration example, electricity purchase costs of CTs are reduced and operators of CPEMS gain profit, proving the feasibility of the model.

1. Introduction
A commercial park (CP) has a function combining eating, accommodation, transportation, shopping and entertainment. With the development of China’s economy, CPs’ electricity consumption grow rapidly. On the one hand, various smart appliances usually controlled by smart devices like smart phones are being used gradually. On the other hand, with the development of photovoltaic and other distributed power technology together with cost reduction, more and more distributed photovoltaic power used by CTs (like restaurants, hotels, etc.) apply for access to the grid[1]. The importance of intelligent CP power consumption and demand side response technology are arousing scholars’ attention.

In traditional power systems, user side is usually deemed as a simple power consumer. However, after the energy crisis in the 1970s, Europe and the United States launched a variety of electricity price systems, and began a research about demand side management (DSM)[2-5]. As the power demand grows, many scholars start to study energy management system (EMS)[6-10]. Through monitoring and collecting users’ power consuming information, EMS can analyse users’ consumption habits and add overall management and optimization to their power consumption. A user’s load optimization model based on consumption efficiency was proposed in [6], which analysed the influence of different consumption habits in the model. Under the background of day-ahead and real-time power markets, a kind of mixed integer programming algorithm was proposed in [7], which focused on charging modes of electromobile with energy storing devices. The general model of EMS with changing electricity prices is discussed in [8], which compares the effects of solving high-dimensional optimization problems using heuristic algorithm and Q-learning algorithm respectively. The power’s continuity and discreteness, transferability and intransferability, interruptibility and non-interruptibility of appliances
are analysed in [10], which studied the modeling and optimization of EMS including appliances such as PVs, energy storing devices and electromobiles.

Papers above concluded that through optimizing users’ power consumption, the peak-valley difference of power systems can be reduced effectively, and so does users’ power costs. The existing researches achieved the modeling of CT appliances, but it’s focused on electrical appliances (electromobiles, storage batteries, PV batteries, etc.). Actually, the behaviour of the thermodynamic equipment such as air conditioners and water heaters has played an important role in the whole CP’s electricity consumption characteristics. More detailed model research should be carried out.

This paper presents an energy management model with multiple CTs in a CP. Models of the transferable appliances; energy storage devices and thermodynamic equipment in CTs are built. The model is applied to a four-CT demonstration example, which shows that the model can achieve an optimal management of CT load, and the validity and feasibility of the model are verified.

2. Energy Management Model for Commercial Parks

2.1. Classifications and Characteristics of Appliances in Commercial Parks

According to the operating characteristics of CTs’ appliances and control methods, CT appliances can be divided into four categories.

- **Non-transferable Appliances**: When the user gives a work order, the uncontrollable appliances must respond immediately without delay. Such appliances’ start/stop and operating power are not controlled by the CPEMS. Such appliances are mostly lighting and entertainment appliances, whose start/stop has a strong randomness, varying with user’s habits. Typical representatives are incandescent lamps, televisions and so on.

- **Transferable Electrical Appliances**: Users can set the working time of such electrical appliances in advance. In the time range set by the user, the CPEMS can be free to arrange the working time of electrical appliances. Further, such appliances can be divided into two categories as interruptible and uninterruptible. The difference between these two categories is whether the appliance can be interrupted when it’s working. For example, the dishwasher can be set to work in a period of time between 19:00 and 22:00, but once the dishwasher starts to work, it cannot be interrupted until the dishwasher completes the job. On the contrary, take electromobiles for example, the user can set to finish the charging between 20:00 and 7:00, and the charging process can be interrupted for many times.

- **Energy Storage Devices**: Because the peak-valley hours and peak-valley generation amount of distributed power is different to that of CPs’ load, clients can buy energy storage devices which will store or release electric power to take full advantage of distributed power. For CTs, considering that the typical peak value of CTs’ load is of kW level, usually lithium batteries and lead batteries can be used as energy storage devices.

- **Thermodynamic Equipment**: It can be seemed as a special kind of transferable appliances. Because of thermodynamic equipment like refrigerator, air conditioner and water heater has a temperature property, the change of internal and external temperature should be taken into consideration while modeling, and heat exchange process should be modeled. To ensure users’ comfort, thermodynamic equipment is often set to work in a temperature range, which is usually set by users and varied with different living habits of users.

2.2. Modeling of CPEMS

In CPEMS, appliances’ operation constraint conditions should be concluded according to different types of appliances’ operation characteristics. The object is to minimize the cost of electricity purchase, and the optimal operation schedule of CTs’ appliances should be made. In this paper, the time interval of CTs’ appliances’ working schedule is 15 minutes.
2.2.1. Distributed generator. For CTs, renewable energy sources like small size wind driven generators, PVs and biomass power generation can be used. Actually, PVs with solar panels are the most popular used clean energy. So in this paper, PV is modelled as an example of distributed generation.

Constraint condition of PV is:

\[ 0 \leq p_{i,t}^{pv} \leq p_{i,t}^{pv,max} \quad (1) \]

Among the equation above, \( p_{i,t}^{pv} \) is the \( i^{th} \) solar panel’s power of generation in the \( i^{th} \) time interval. \( p_{i,t}^{pv,max} \) is the \( i^{th} \) solar panel’s maximum power of generation in the \( i^{th} \) time interval, which can be obtained by making the solar panel work in Maximum Power Point Tracking (MPPT) mode. When CTs’ smart grid and power grid operate together, SEMS can let PVs work in MPPT mode, selling extra electricity generated by PVs to power grid to gain more profit.

2.2.2. Non-transferable appliance. Non-transferable appliances are of strong randomness, greatly influenced by different users’ living habits. They’re the direct result of users’ “electricity consumption modes”. Based on users’ history electricity consumption information, typical load curves of non-transferable appliances can be obtained through clustering algorithm in [11]. Let the \( i^{th} \) CT’s typical power of non-transferable appliances in the \( i^{th} \) time interval be \( EL_{i,t}^{nc} \).

2.2.3. Transferable appliance. Let the \( i^{th} \) transferable appliance’s working condition in \( i^{th} \) time interval be \( u_{i,t}^{e}, u_{i,t}^{s} \) is a binary variable. A value of 0 stands for shutdown status, and value of 1 stands for operating status. Constraint condition of Transferable appliance is:

\[ u_{i,t}^{s} = 0, \forall t < t_{i}^{e} \ or \ t > t_{i}^{e} \quad (2) \]

\[ \sum_{t=0}^{\infty} u_{i,t}^{s} = D_{i}, \forall i \quad (3) \]

\[ u_{i,t}^{e} - u_{i,t-1}^{e} - u_{i,k}^{e} \leq 0, \forall t \leq t_{i}^{on} + t - 1 \quad (4) \]

Among the equation above, \( t_{i}^{e} \) is the earliest start time of the \( i^{th} \) transferable appliance, and \( t_{i}^{e} \) is the latest shutdown time of it. \( D_{i} \) is the time that the \( i^{th} \) transferable appliance needs to finish working. \( t_{0} \) and \( t_{end} \) respectively stands for SEMS’s start time and end time for planning. \( T_{i}^{on} \) is minimum working time after transferable appliance booting.

Equation (2) indicates that transferable appliance can only complete its work within the time period specified by the user. \( t_{i}^{s} \) and \( t_{i}^{e} \) is specified by the user according to his or her own habits, and the user can change them at any time according to the need. For example, the user can take the washing machine as a transferable appliance which is opened to the operators of CPEMS, and specify the time that the washing machine can work between 18:00 to 22:00 every day. This schedule is informed to the CPEMS operator at the planning stage before day. One day the user needs to complete the laundry work between 10:00 to 12:00 for some reason. Then he needs to notify the CPEMS operators at real-time adjustment stage. The CPEMS operators will adjust the work plan to meet the user's demand for electricity. Equation (3) indicates that the start-up time of the transferable appliance in one day is equal to the time required to complete the work, thus ensuring the completion of the task. The value of \( D_{i} \) is determined by the appliance itself. Equation (4) is constrained by the minimum operating time of the transferred electrical appliance. As for uninterruptible loads, \( T_{i}^{on} = D_{i} \), ensuring that electrical appliances cannot be stopped until it is finished after booting. As for interruptible loads, \( T_{i}^{on} < D_{i} \).
which means that the appliance can be started and stopped several times. $T_{im}$ is decided by the electrical characteristics of the appliance itself.

### 2.2.4. Energy Storage Device

Energy storage device is not a general sense of appliances, and can be seen as the special equipment which can minimize the cost of power purchasing. Therefore, start and shutdown of energy storage devices with their power should be controlled by the CPEMS operators.

**Constraint condition of Energy storage device is:**

$$soc_{i,t} = soc_{i-1,t} + \frac{p_{i,t}^{ch} \cdot \Delta t \cdot \eta_{ch} - p_{i,t}^{dis} \cdot \Delta t}{C_i}$$  \hspace{1cm} (5)$$

$$soc_{i,min} \leq soc_{i,t} \leq soc_{i,max}, \forall i, t$$  \hspace{1cm} (6)$$

$$soc_{i,end} \geq \epsilon_i, \forall i$$  \hspace{1cm} (7)$$

$$\sum_{i} p_{i,t}^{dis} \cdot \sum_{i} p_{i,t}^{ch} = 0, \forall t$$  \hspace{1cm} (8)$$

Among the equation above, $soc_{i,t}$ is the state of charge (SOC) of the $i^{th}$ energy storage device in the $i^{th}$ time interval. $p_{i,t}^{ch}$ and $p_{i,t}^{dis}$ is charging power and discharge power of the $i^{th}$ energy storage device in the $i^{th}$ time interval respectively. $\eta_{ch}$ is energy conversion efficiency of energy storage device. $C_i$ is the volume of the $i^{th}$ energy storage device. $\epsilon_i$ is the $i^{th}$ energy storage device’s minimum SOC at the end of the planning period. $soc_{i,min}$ and $soc_{i,max}$ stands for minimum and maximum charge state respectively of $i^{th}$ energy storage device.

Equation (6) is a constraint on the charge state of the energy storage system. For chemical battery type energy storage systems, the larger the depth of discharge will generally shorten the battery life, which is particularly evident for lithium-ion batteries. Therefore, the general battery type energy storage system usually set the maximum and minimum state of charge to protect the battery. $soc_{i,min}$ and $soc_{i,max}$ will be provided by the energy storage system manufacturer. Equation (7) ensures that at the end of the optimization period, the energy storage device maintains a certain amount of energy to ensure the ability to adjust for the next optimization period. Equation (8) constrains that a system with multiple energy storage systems cannot be in a state of charge and discharge at the same time. If part of the energy storage device is in the charging state, and the other part of the energy storage device is also in the discharge equipment, this is also a behavior of energy wasting. However, the formula (8) is essentially a quadratic constraint with multiple cross terms. This type of constraint will destroy the convexity of the problem and cause the problem to be difficult to solve. To solve this problem, flag variables $f_{i}^{ch}$ is set. $f_{i}^{ch}$ indicates whether the energy storage device can be recharged in the $i^{th}$ time period. A value of 0 means that it can be recharged, while value of 1 means not. Equation (8) can be re-expressed as:

$$0 \leq p_{i,t}^{ch} \leq f_{i}^{ch} \cdot p_{i}^{ch,max}, \forall i$$

$$0 \leq p_{i,t}^{ch} \leq (1 - f_{i}^{ch}) \cdot p_{i}^{dis,max}, \forall i$$  \hspace{1cm} (9)$$

### 2.2.5. Thermodynamic Equipment

The key to the modelling of thermodynamic equipment is how to describe the heat exchange process. Take air conditioning as an example, assume that the internal temperature of the room is $T_r$ (ignoring the room temperature difference), outdoor temperature is $T_{out}$. The heat change in the room is caused by the heat exchange between the air conditioner and the room as well as the heat exchange between the room and the outside. The whole process can be described as:
\[
\frac{dT'(t)}{dt} = \frac{1}{M_{\text{air}} \cdot c} \left[ \left( \frac{dQ(t)}{dt} \right)_{\text{HVAC}} - \left( \frac{dQ(t)}{dt} \right)_{\text{loss}} \right]
\]
\[
\left( \frac{dQ(t)}{dt} \right)_{\text{HVAC}} = \sum_i \eta_i^{\text{he}} \cdot p_i^{\text{he}} - \eta_i^{\text{co}} \cdot p_i^{\text{co}}
\]
\[
\left( \frac{dQ(t)}{dt} \right)_{\text{loss}} = \frac{T'(t) - T_{\text{out}}(t)}{R_{\text{eq}}}
\]

Among the equation above, \(M_{\text{air}}\) is the quality of the air in the room. \(c\) is heat capacity per unit mass of air at standard pressure. \(p_i^{\text{he}} / p_i^{\text{co}}\) is the heating/cooling power of the \(i^{th}\) thermodynamic equipment. \(\eta_i^{\text{he}} / \eta_i^{\text{co}}\) is the heating/cooling efficiency of the \(i^{th}\) thermodynamic equipment. \(R_{\text{eq}}\) is the equivalent thermal resistance of the room at that time. \(\left( \frac{dQ(t)}{dt} \right)_{\text{HVAC}}\) is the heat exchange between the air conditioner and the indoor unit per unit time. \(\left( \frac{dQ(t)}{dt} \right)_{\text{loss}}\) is the heat exchange between the outdoor unit and indoor unit per unit time. It should be noted that \(c\) is a thermodynamic constant. \(M_{\text{air}}\) is related to the size of the room. For a CT, \(M_{\text{air}}\) can be regarded as constant. \(R_{\text{eq}}\) is related to the current room type and ventilation state. Assume that \(p_i^{\text{he}}\) and \(T_{\text{out}}\) is a constant over a period of time. Solving the equations (10)-(12) and discretizing the results, a formula can be obtained:
\[
T_{r,i+1} = R_{\text{eq}} \cdot (1 - K_h) \left( \eta_i^{\text{he}} p_i^{\text{he}} - \eta_i^{\text{co}} p_i^{\text{co}} \right) + T_{r,i} \cdot K_h + (1 - K_h) \cdot T_{\text{out}}
\]

Among the equation above,
\[
K_h = \exp \left( \frac{-t}{M_{\text{air}} \cdot c \cdot R_{\text{eq}}} \right)
\]

Similar results have been reported in [9] [10], but they do not distinguish the heating and cooling power of air-conditioning equipment, which limits the application of the model. Generally, in order to ensure the comfort of the user, the user can set the upper and lower limits of the indoor temperature, the CPEMS operator will keep the indoor temperature within the range:
\[
T_{r,min} \leq T_{r,i} \leq T_{r,max}, \forall t
\]

### 2.3. Operational Strategy of CPEMS

The user's distributed power generation system will meet the user's own needs of electricity preferentially, and the extra electricity can be selling to the power grid to gain more profit. If the PVs' equipment and energy storage devices are not sufficient to meet the CT electricity demand, users need to purchase electricity from the grid. CPEMS operators need to ensure the power balance of CTs’ smart grid by selling and buying electricity from the grid. Constraint condition of it can be described as:
\[
p_{t}^{\text{buy}} - p_{t}^{\text{sell}} = \sum_i \left( EL_i^c + \sum_i u_i^c \cdot p_i^{c} + \sum_i (p_i^{\text{co}} + p_i^{\text{he}}) + \sum_i (p_i^{\text{he}} - p_i^{\text{dis}}) - \sum_i p_i^{\text{pv}} \right), \forall t
\]

Among the equation above, \(p_{t}^{\text{buy}} / p_{t}^{\text{sell}}\) is the electric power that CPEMS buys or sells to the grid in the \(t^{th}\) time interval. This electric power is the sum of the power purchased and sold by the CTs and power grid who is responsible for the CPEMS operator. As a result, the CPEMS operator cannot
simultaneously purchase and sell electricity. So let $f_i^g$ be a variable to show whether electricity can be purchased or not in $t^{th}$ time interval.

Constraint condition of $f_i^g$ is:

$$0 \leq p_i^{\text{buy}} \leq f_i^g \cdot p^{\text{buy, max}}, \forall t \quad 0 \leq p_i^{\text{sell}} \leq (1 - f_i^g) \cdot p^{\text{sell, max}}, \forall t$$  \hspace{1cm} (17)

Among the equation above, $p^{\text{buy, max}}$ is the CPEMS operator’s maximum purchase power, determined by the distribution network power supply capacity. $p^{\text{sell, max}}$ is the CPEMS operator’s maximum sold power, determined by the capacity of the CTs’ smart grid’s outlet inverter.

CPEMS operator's operating goal is to achieve the lowest cost of electricity purchase, under the premise that meeting the needs of multiple CTs’ electricity demand. It can be described as:

$$\min \sum (p_i^{\text{buy}} \cdot c_i^{\text{buy}} - p_i^{\text{sell}} \cdot c_i^{\text{sell}}) \Delta t$$  \hspace{1cm} (18)

Among the equation above, $c_i^{\text{buy}} / c_i^{\text{sell}}$ is the real-time price at which the CPEMS operator buys / sells electricity to the grid in the $t^{th}$ time interval. Equations (1)-(17) are the constraints of the optimization problem. As a whole, the problem can be expressed as a mixed integer linear programming problem.

3. Demonstration Examples

3.1. Parameter Settings

The data presented in this paper is from a commercial park of a smart grid demonstration project. Four CTs in the commercial park are selected as model CTs with solar panels and energy storage devices installed.

According to the proposed CPEMS model, historical data of power consumption should be collected first during pre-research phases. After then, obtain the typical electricity consumption pattern of uncontrollable appliances by calculation. Such curves of the four CTs are shown in figure 1. The transferable load parameters, energy storage devices parameters and thermodynamic equipment parameters of the four CTs are shown in Table 1-3 of appendix.

Exposed to the sunlight, solar panel’s generation data and outdoor temperature conditions is shown in Figure 2. The outdoor temperature can be obtained from the local meteorological bureau, and the PV power can be calculated from the daylighting condition data. The electricity purchasing price is different in peak and valley hours. The time between 6:00 and 22:00 is peak hours, and the price is 0.56 Yuan/kWh. The time between 22:00 to 6:00 of the next day is valley period, and the price is 0.28 Yuan/kWh.
The demonstration examples use MATLAB 2014a and YALMIP [12] to complete the calculations, where the solution for mixed integer programming is done using IBM ILOG CPLEX 12.6. All calculations are done on a personal laptop with a 2.6G clock speed and 8G of memory with a processor model i5-4219M.

4. Result Analysis
In order to verify the effectiveness of the proposed energy management model, the following two situations are demonstrated and compared.

- **Situation 1**: No CPEMS participates. All the transferable load can begin to work at allowed working time. When the PV power is supplied to the user, the excess electricity is sold to the power grid. The electricity price is 0.3 Yuan/kWh for peak hours and 0.15 Yuan/kWh for valley period.

- **Situation 2**: The users make an agreement with the CPEMS operators and the operators will arrange the transferable load’s and energy storage devices’ operation. On the basis of purchasing power and selling electricity, the operators can reduce 7% of the electricity purchasing cost and give a subsidy of 7% of the electricity sales to the users, and subsidize the users' energy storage capacity according to 0.02 Yuan/(kWh·day).

In the two situations, the CTs’ electricity costs are shown in Table 1. The operation of CPEMS in situation 2 is shown in Table 2.

### Table 1. Electricity costs in different situation (in Yuan)

| Clients | Situation 1 | Situation 2 |
|---------|-------------|-------------|
| CT A    | 2.46        | 1.14        |
| CT C    | 3.50        | 2.31        |
| CT C    | 5.61        | 3.03        |
| CT D    | 4.23        | 2.02        |
| **Total** | **15.80**  | **8.50**    |

### Table 2. The profit table of CPEMS operators (in Yuan)

| Electric price with subsidy | Subsidy | Electric price with subsidy | Subsidy | Purchasing price from grid | Profit |
|-----------------------------|---------|-----------------------------|---------|---------------------------|--------|
| Electricity purchasing      | 15.35   | 4.094                       | 1.973   | 0.780                     | 0.58   |
| Electricity selling         |         | Energy storing              |         | 8.50                      |        |
| Energy storing              |         | Purchase                     |         | 7.92                      |        |
| Subsidy                     |         | Subsidy                      |         |                           |        |

It can be seen that in Situation 2 where the CPEMS participates, most of the users' electricity purchasing costs are significantly lower than that in Situation 1 due to the subsidy given by the CPEMS operator. In this case, CTs are willing to sign agreement with the CPEMS operator to obtain the subsidy. Also, in this situation, the CPEMS can reduce the total cost of purchasing power by optimizing the electricity plan of the four CTs, in spite that subsidizing the user increases the operating costs. Generally speaking, CPEMS is profitable. This shows that the operating mode in this paper can help users and CPEMS achieve a win-win situation.

5. Conclusions
This paper presents a multi-CT energy management model with thermodynamic equipment. The demonstration examples’ result shows that under CPEMS mechanism, more PV power will be
consumed locally and users’ costs are reduced. At the same time, the CPEMS operator gains profit, achieving a win-win situation.

In this model, the effect of the uncertainty of the renewable energy is not taken into account. Using the mathematic tools such as robust optimization and stochastic programming to quantitatively consider the influence of PV forecast error on the specified electricity plan, and improving the robustness of the electricity plan is the direction of next research.

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7. Appendix

**Appendix Table 1. Parameters of Transferable Appliances**

| Number | CT | Appliance name          | Working time duration (min) | Earliest working hour | Latest working hour | Minimum working time duration (min) | Power (kW) |
|--------|----|-------------------------|----------------------------|-----------------------|---------------------|-------------------------------------|------------|
| 1      | A  | disinfection cabinet    | 60                         | 09:00                 | 19:00               | 25                                  | 1.5        |
| 2      | A  | washing machine         | 50                         | 09:00                 | 17:00               | 25                                  | 0.7        |
| 3      | C  | washing machine         | 60                         | 11:00                 | 23:00               | 50                                  | 0.8        |
| 4      | B  | water heater            | 200                        | 1:00                  | 8:00                | 10                                  | 1.6        |
| 5      | C  | dishwasher              | 45                         | 8:00                  | 18:00               | 20                                  | 0.6        |
| 6      | C  | dryer                   | 85                         | 09:00                 | 19:00               | 10                                  | 0.4        |
| 7      | C  | electromobile           | 120                        | 16:00                 | 23:00               | 30                                  | 1.3        |
| 8      | C  | washing machine         | 250                        | 1:00                  | 9:00                | 25                                  | 1.4        |

**Appendix Table 2. Parameters of Energy Storage Devices**

| Number | CT | Maximum charging power (kW) | Maximum discharging power (kW) | Charging efficiency | Capacity (kWh) | Minimum state of charge | Maximum state of charge | Initial state of charge |
|--------|----|-----------------------------|--------------------------------|---------------------|----------------|-------------------------|-------------------------|------------------------|
| 1      | A  | 3                           | 2.1                            | 0.89                | 6              | 0.12                    | 0.85                    | 0.50                   |
| 2      | B  | 2.2                         | 1.8                            | 0.85                | 7              | 0.12                    | 0.92                    | 0.50                   |
| 3      | C  | 5                           | 3.3                            | 0.88                | 15             | 0.16                    | 0.92                    | 0.50                   |
| 4      | D  | 4.2                         | 2.8                            | 0.89                | 11             | 0.16                    | 0.90                    | 0.50                   |

**Appendix Table 3. Parameters of Thermodynamic Equipment**

| Number | CT | Equivalent thermal resistance | Initial temperature | Minimum setting temperature | Maximum setting temperature | Maximum cooling power (kW) | Maximum heating power (kW) |
|--------|----|-------------------------------|---------------------|-----------------------------|-----------------------------|---------------------------|---------------------------|
| 1      | A  | 35                            | 26                  | 17                          | 27                         | 2.9                       | 2.4                       |
| 2      | B  | 20                            | 26                  | 19                          | 27                         | 1.9                       | 1.7                       |
| 3      | C  | 14                            | 26                  | 19                          | 27                         | 1.5                       | 0.7                       |
| 4      | D  | 25                            | 26                  | 23                          | 28                         | 3.2                       | 5.2                       |

8. References

[1] TONG Huiming, DENG Lan, PAN Shuangshuang. Introduction of Zhejiang homes distributed photovoltaic power generation projects, network management and technical innovation [A]. China Electricity Council of Science and Technology Development Service Center.

[2] YAAGOUBI N, MOUTTAH H T. User-aware game theoretic approach for demand management[J]. Smart Grid, IEEE Transactions on, 2015, 6(2): 716-725.

[3] STEPHENS E R, SMITH D B, MAHANTI A. Game theoretic model predictive control for distributed energy demand-side management[J]. Smart Grid, IEEE Transactions on, 2015, 6(3): 1394-1402.

[4] ESTHER B P, KUMAR K S. A survey on residential Demand Side Management architecture, approaches, optimization models and methods[J]. Renewable & Sustainable Energy Reviews, 2016, 59:342-51.

[5] GHAZEMI A, SHAYEGHI H, MORADZADEH M, et al. A novel hybrid algorithm for electricity price and load forecasting in smart grids with demand-side management[J]. IEEE Transactions on Power Systems, 2016.

[6] JINGHUAN M, CHEN H H, LINGYANG S, et al. Residential load scheduling in smart grid: A cost efficiency perspective [J]. IEEE Transactions on Smart Grid, 2016, 7(2): 771-84.
[7] JIN C, TANG J, GHOSH P. Optimizing electric vehicle charging with energy storage in the electricity market[J]. Smart Grid, IEEE Transactions on, 2013, 4(1): 311-320.

[8] LIANG Y, HE L, CAO X, et al. Stochastic control for smart grid users with flexible demand [J]. Smart Grid, IEEE Transactions on, 2013, 4(4): 2296-308.

[9] HUBERT T, GRIJALVA S. Modeling for residential electricity optimization in dynamic pricing environments [J]. Smart Grid, IEEE Transactions on, 2012, 3(4): 2224-31.

[10] ZHOU L, Modeling and optimal dispatch for residential load based on home energy management system under time-of-use pricing[J], Power System Technology, 2015, 02(39): 367-74.

[11] HINO H, SHEN H, MURATA N, et al. A versatile clustering method for electricity consumption pattern analysis in homes [J]. Smart Grid, IEEE Transactions on, 2013, 4(2): 1048-57.

[12] LÖFBERG J. YALMIP: A toolbox for modeling and opti-mization in MATLAB[C]//Computer Aided Control Sys-tems Design, 2004 IEEE International Symposium on. IEEE, 2004: 284-289.