The Strategy of Integrated Demand Response Considering the Interaction Between Superior Power Grids and Factories

Yuhong Zhang1, Yi Luo1, Yingying Deng1, Xiao Wang2* and Libo Lian2

1 State Grid Sichuan Economic Research Institute, Chengdu, Sichuan, 610000, China
2 Tsinghua Sichuan Energy Internet Research Institute, Chengdu, Sichuan, 610000, China
*Corresponding author’s e-mail: 529747343@qq.com

Abstract. With the development of the energy internet, the integrated demand response (IDR) has become a key technology for the establishment of a benign interaction between industrial parks and factories. As a result, a comprehensive demand response strategy is proposed in this paper. Firstly, taking minimization of cost, optimal scheduling model for factory is constructed, as the basis for interaction. Then, the maximum adjustable ability of the user is excavated according to the peak regulation of the park based on the IDR model. The results show that the energy utilization efficiency of the users is improved by the synergistic complementarity, and the industrial park can provide the auxiliary services for the power grid.

1. Introduction

Under the background of the energy internet [1-2], the decentralized energy market and energy network structure will make the traditional demand response (DR) gradually develop towards the direction of integrated demand response (IDR). IDR can fully tap the potential of adjustment ability of load on demand side to improve the utilization of equipment in the energy hub, and reduce the energy cost [3].

At present, there are few studies on the comprehensive demand response aiming for plant [4-8]. A reasonable design considering IDR strategy is an important means to achieve the benign interaction between distribution network and industrial users and has good popularization value in the industrial park. This paper proposes a comprehensive demand response strategy for plant interaction with industrial parks. Firstly, as a basis to participate in interaction, the self-optimization model is built based on the construction of plant which can implement energy optimization management. On this basis, the plant control system will upload the energy curve to industrial park which can determine whether the peak shaving demand exist. If there is a demand for peak shaving, the IDR is started, which aims to both satisfy the demand for peak cutting and the plant energy economy. Finally, the maximum control capacity of the plant and the new energy use strategy is obtained, plant makes demand side quotation based on user satisfaction.
2. Self optimization model

2.1. Optimization index

1) Cost of Using Energy

Based on the schematic diagram of typical plant is shown in this paper as shown in Figure 1. The objective function is to minimize operating cost $C_{ATV}$ include the cost of operation and maintenance $C_{OM}$, the depreciation cost of energy storage $C_{bw}$ and the cost of power purchase $C_{grid}$.

$$MinC_{ATV} = C_{OM} + C_{bw} + C_{grid}$$

2) User satisfaction

User satisfaction with electricity will affect the enthusiasm of the user to participate in the IDR. User satisfaction can be expressed as [9]:

$$S_{user} = \frac{1}{2}S_{load} + \frac{1}{2}S_{new}$$

$$S_{load} = 1 - \frac{R_{load,shift}}{R_{load,all}}$$

$$S_{load} = (R_{one} + R_{BESS}) / R_{all}$$

$S_{load}$ indicates power purchase satisfaction, $S_{new}$ indicates power supply satisfaction, $R_{load,shift}$ indicates load transfer, $R_{one}$ indicates direct supply of renewable energy to load energy, $R_{BESS}$ indicates renewable energy supplies load energy after storage, $R_{all}$ indicates total energy supply for renewable energy.

2.2. Constraint condition

1) The balance of total power:

$$P_{buy} + P_{PV} = P_{AC-load} + P_{DC-load} + P_{BESS} + P_{ice} + P_{CT}$$
\( p_{\text{bg}, t} \) indicates Power purchasing power from power grid of period \( t \), \( p_{\text{pv}, t} \) indicates photovoltaic power, \( p_{\text{dc}, \text{load}, t} \) indicates DC load, \( p_{\text{ac}, \text{load}, t} \) indicates communication load, \( p_{\text{chrg}, t} \) indicate charging power of electrical energy storage, \( p_{\text{ice}, t} \) indicates the power consumption of the cold storage device, it is positive when cold storage and negative when cooling, \( p_{\text{ct}, t} \) is the power consumption of the cooling tower.

2) Electric energy storage constraint

\[
\begin{aligned}
S_{i, ES, t}^{t+1} &= (1 - \sigma_{ES}^e) S_{i, ES, t}^t + \left[ \eta_{ES}^e W_{s, i, t}^t - \frac{W_{r, i, t}^t}{\eta_{ES}^r} \right] T \\
S_{i, ES, t}^\text{min} &\leq S_{i, ES, t}^t \leq S_{i, ES, t}^\text{max} \\
0 &\leq W_{r, i, t}^t \leq W_{r, i, t}^\text{max}
\end{aligned}
\]  

\( S_{i, ES, t}^t \) indicates energy storage of electrical energy storage \( i \) at time period \( t \), \( \sigma_{ES}^e \) indicates self loss coefficient of energy storage, \( \eta_{ES}^e \) and \( \eta_{ES}^r \) indicate charging efficiency and discharge efficiency of energy storage, \( S_{i, ES, t}^\text{max} \) and \( S_{i, ES, t}^\text{min} \) is the maximum and minimum storage capacity of energy storage equipment, \( W_{s, i, t}^\text{max} \) and \( W_{r, i, t}^\text{max} \) indicate maximum charging and discharging power of energy storage equipment.

3) Energy conversion equipment constraints

\[
w_{\text{out}, s, t}^t = W_{\text{in}, s, t}^t \eta_s^t
\]

\( w_{\text{out}, s, t}^t \) and \( W_{\text{in}, s, t}^t \) indicate the output power and input power of the energy conversion equipment at time \( t \), \( \eta_s^t \) indicates energy conversion efficiency.

3. IDR Model considering the interaction with industrial park

The interaction between the plant and the industrial park follows the following three principles: (1) without peak demand, every plant operates with the self-optimization strategy of operation; (2) if the industrial park has a peak demand, park issued peak demand and plant quoted price according to its peak by the cost. Then park select the plant to respond and its peak volume; (3) the plant selected respond to the park according to the contract peak volume. The specific IDR strategy is shown in Figure 2 when the industrial park is interacting with the plant.
3.1. Comprehensive demand response capability

3.1.1. Optimization goal
The objective function is multi-objective, which uses the maximization of all adjustable capacity to meet the peak shaving demand and minimizes the cost of electricity consumption.

\[
\text{Min} \lambda_1 \sum_{t=t_0}^{t_1} |P_{IDR}^t - P_0^t| + \lambda_2 C_{ATC}
\]

(6)

\(t_0 \rightarrow t_1\) indicates peak shaving time, \(P_{IDR}^t\) indicates the power of plant gateway after interaction at \(t\) time period, \(P_0^t\) indicates the target power of the optimized plant, \(\lambda_1, \lambda_2\) indicate weight coefficient, \(\lambda_1 \gg \lambda_2\).

3.1.2. Constraint condition
Compared with the self-optimization scheduling of factories, the following constraints are added:

\[
P_{IDR}^t \leq P_1^t
\]

(7)

\[
P_{buy}^t - P_{IDR}^t \leq \Delta P_o^t
\]

(8)

\(P_1^t\) indicates the upper limit of power at the closing time of the non-clipping period from the park, \(\Delta P_o^t\) indicates peak shaving requirement of the park in peak shaving period.

3.2. User IDR quotation
To make the users of each plant actively participate in the comprehensive demand response to the interaction with the park, a form of compensation quotation considering user satisfaction is proposed.

\[
B_i = \lambda_s (2 \cdot S_{user}^i) \left( C_{ATC}^i - C_{ATC}^d \right)
\]

(9)
indicates compensation for the number i plant, $C_{AC}^i$ and $C_{ATC}^i$ indicate the cost of energy use in the number I plant after optimization and interaction, the difference between the two is the response cost of the plant's comprehensive demand, $\lambda_i$ indicates weight coefficient of user satisfaction, $S_{user}^i$ indicates user satisfaction after user participation in the number i plant, $0 \leq S_{user}^i \leq 1$.

Finally, based on meeting peak demand and the goal of minimum compensation cost, parks choose the plant involved in peak shaving and peak shaving capacity to respond to higher power auxiliary service demand according to the peak shaving capacity and quoted price from various factories to cut the price.

4. Numerical experiments
Solve plant’s self-optimization model and optimal scheduling strategy of every period (storage charge and discharge, the ice / water storage load distribution) as shown below.

![Fig3. SOC of battery](image)

![Fig4. Ice storage device cooling load distribution](image)

Obviously, the optimization based on the self-optimization model, promote energy at different levels of energy in the system switching and cascade utilization. It also improves the efficiency of the whole plant, and optimize the use of local energy ratio. At the same time, users can adjust their different types of energy use requirements and use habits according to the price signal, thus reducing
their own cost of energy use. After optimizing with the self-optimization model, the electricity cost was saved by 9.1%.

After that, the self-optimization energy consumption curve is uploaded to the energy management system of the park. The power limit assessment is carried out by the energy management system of the park. If there is a power over-limit, it is necessary to consider the comprehensive demand response between the industrial park and the plant. Taking 2 typical factories of industrial park as an example, a case study is carried out. It is assumed that the peak shaving period of the park is 18:00-19:00, the demanded peak shaving power is 3MW, and the upper limit of the gate power of non-clipping period is 6.5MW.

Through solving the comprehensive demand response model of the interaction between industrial park and the plant, we can get a comprehensive demand response strategy of every period when peak shaving is needed (energy discharging strategy, the ice / water cold storage, load distribution) and participate in the changes before and after the interaction of power points.

![Fig5. The comparison of battery SOC](image1)

![Fig6. The comparison of ice storage device cooling load distribution](image2)
Fig7. Demand change in plant1

It has successfully responded to the interactive demand of the park in the 18:00-19:00 period, and provided the peak shaving capacity of 2MW because of the plant has sufficient control ability. The operation strategy of energy equipment changed greatly before and after considering the comprehensive demand response of industrial park and plant interaction. After the interaction, the battery is discharged with high power, and at the same time the cooling device is cooled with ice to respond to the demand of peak cutting.

If the user satisfaction weight coefficient is 1.2, the IDR quotations of plant 1 and plant 2 providing peak shaving capacity of 80%, 60%, 40% and 20% ratios for park selection. As shown in Table 1 and table 2.

| Peak-cutting capacity | Operating cost (RMB) | User satisfaction | IDR Quotation (RMB) |
|-----------------------|----------------------|-------------------|---------------------|
| self-optimization     | 84941.83             | 0.920             | /                   |
| 3MW                   | 86480.71             | 0.927             | 1981.46             |
| 2.4MW                 | 85956.68             | 0.929             | 1304.29             |
| 1.8MW                 | 85465.82             | 0.923             | 677.20              |
| 1.2MW                 | 85157.53             | 0.926             | 277.99              |
| 0.6MW                 | 84965.5              | 0.919             | 30.70               |

Because plant 2 has less adjustable resource capacity and less control capability, it can provide 1.5MW peak shaving capacity at most during 18:00-19:00. We can see that when plant needs to reduce the peak shaving capacity, it can use more adjustable capacity to meet its own economic requirements and the IDR cost is reduced. Therefore, for the park, based on meeting the total peak shaving volume, it is the best economy for each plant to take the minimum peak shaving capacity.

Finally, the park selects the plant 1 to cut the peak 1.8MW, the plant 2 peeling peak 1.2MW. It is calculated that the IDR compensation for the park needs to be paid 1399.29 yuan. It has achieved a win-win situation between the higher power grid and the industrial users.
5. Conclusions and future work

In this paper, a comprehensive demand response strategy considering the interaction between industrial parks and factories is proposed for industrial parks. Firstly, the construction of the plant self-optimization model enables the energy to achieve cascade utilization and switch in different levels of energy system. It also improves the overall efficiency of the plant and optimize the local energy efficiency. Based on this, IDR model considering the interaction between plant and industrial park can be constructed. It allows users have more capacity of "virtual energy unit", so that they can further explore and utilize the regulation capacity of plants' distributed resources, such as source, reservoir, load, in response to the demand of higher power grid. Then, A form of IDR compensation considering user satisfaction is put forward. It reasonably compensates the impact of industrial users' economy and satisfaction based on meeting the demand of power grid peak shaving and promotes the benign interaction between higher power grid and industrial users. Finally, having realized the win-win of the Power Grid Corp and the industrial users, it has a good promotion value in the industrial park. In the follow-up research, the influence of the uncertainty of user behavior on the IDR strategy will be considered.

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