On the Architecture of Smart and Orderly Power Consumption Management Platform Based on Smart and Orderly Power Consumption Devices

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Abstract

In view of the problems like poor dynamic flexibility of grid, and the lack of real-time information interaction between power consumption devices and power supply devices, and among power consumption devices, this paper puts forward a smart and orderly power consumption management platform based on smart and orderly power consumption devices through R&D of smart and orderly power consumption which centers on smart grid and aims at utilizing low-carbon energy, and also proposes the optimization model. Dedicated to achieving the real-time information interaction between power consumption devices and power supply devices, and among power consumption devices, the platform uses smart and orderly power consumption management devices to send information to the smart and orderly power consumption management system through a wired or wireless network—the network itself and the remote smart and orderly power consumption management system are wired together or connected wirelessly—so that the automatic electrical load of power consumption equipment could be adjusted in a smart and orderly fashion at the side of transformer-based consumers in accordance with the electrical load curve of the distribution network.

Keywords: smart and orderly power, optimization model, power consumption management system

1. INTRODUCTION

With the development of the national economy, the increase of population and the advancement of urbanization, the continued growth in energy demand have brought more and more challenges to the energy supply to the society (Huang,2015). Centering on smart grid and targeted at realizing low-carbon energy, a new round of world energy revolution has taken hold. As an important part of smart grid construction, smart power consumption requires the transition from the era of extensive use of electricity into the era of intensive use of electricity, and into the era of harmonious use of electricity. Orderly power consumption (Xiao,2012; Wang and Hu,2012; Lu et al.,2013; Zhu and Chen,2014) is also an important part of smart power consumption. Based on automated demand response, the
orderly power consumption technology is capable of realizing the following through the construction of orderly power consumption and flexible electrical load: real-time interaction (El-Khazali and Tawalbeh, 2016) and response between the grid and consumers, enhancing the integrated service capability of the grid, improving power consumption efficiency, promoting energy conservation and emission reduction, increasing the economic efficiency of power equipment operation, and saving power investment.

Based on automated demand response, the orderly power consumption (Huang et al., 2015) technology is the key to the construction of intelligent parks, orderly charging of electric vehicles, grid connection of new energy, intelligent residential communities, and smart homes, and also the mirror of the application of the demonstration projects in the field of smart power consumption. Studies on the orderly power consumption technology based on automated demand response help improve the service level of the high/low-voltage consumers, give technical support for the orderly charging management of the electric vehicles, provide technical means and management methods for grid connection of clean new energy sources like solar power generation and wind power generation, and unveil new measures of energy conservation and emission reduction for intelligent parks, intelligent residential communities and smart homes. Meanwhile, the research is capable of upgrading power distribution and consumption management at the low-voltage side, turning passive power consumption to positive power consumption, improving the quality power consumption services, shifting and averting peak loads, and raising the efficiency of power equipment.

2. EXISTING TECHNICAL PLAN

Currently, orderly power consumption is mainly managed by manual control, supplemented by automatic control. Various measures are being adopted to achieve orderly power consumption management of large customers, such as electric quantity control, power control, factory shutdown, etc., and to adjust grid load by peak shifting and clipping. However, there is rarely any product or technical plan based on the automated demand response at the consumer-side.

The demand-side management guides consumers to adjust the mode of production and operation by widening the gap between the time-of-use rates at peak time and valley time, implementing interruptible load price, etc. Besides, some incentive policies and measures are also taken to promote energy-saving equipment such as energy-saving lamps, frequency conversion motors and water pumps, and high-efficiency transformers (Zheng, 2014). To achieve orderly power consumption, legal, administrative, economic, technical and other means should be adopted to strengthen power consumption management, and change the way of power consumption among consumers. From peak shifting, peak averting, rotational use, to negative control rationing, a series of measures should be resorted to avoid unplanned power cuts and standardize the order of power consumption, thereby minimizing the adverse impact from seasonal and periodical power supply and demand contradictions to the society and enterprises.
With the construction of smart grid, the load type on the consumer side is becoming more and more complicated. Distributed generation, energy storage, charging and other devices are entering common households. The phenomenon poses some new challenges to researchers, namely, how to coordinate the use of these devices and avoid negative impacts to the distribution network. Hence, it is necessary to explore the orderly operation of power consumption equipment to further promote technical development in the field of smart power consumption.

3. EXISTING TECHNICAL PROBLEMS

Currently, orderly power consumption control and management equipment and systems are mostly management equipment centering on load control and management terminals and systems dedicated to power consumption information. Manual control is the predominant management method, supplemented by automatic control. Various measures are being adopted to achieve orderly power consumption management of large customers, such as electric quantity control, power control, factory shutdown, etc., and to achieve load leveling by adjusting grid load. Nevertheless, the current grid is a rigid system with poor dynamic flexibility (Heydt and Pierre, 2016; Pierre and Heydt, 2014). Manifested by the rigidity for power sources and power consumption equipment to enter/exit the grid, by the fixed transmission mode of power energy, and by the absence of real-time information interaction between power consumption devices and power supply devices, and among power consumption devices, the poor dynamic flexibility of the grid makes it impossible to resolve the local load changes caused by simultaneous charging of several electric vehicles with the same transformer, to resolve the local absorption and grid connection of transformer-based new energy power generation, to resolve the high load operation of air-conditioners on hot summer days, to resolve the huge power consumption when a lot of power consumption equipment start at the same time during the peak period, or resolve the strains on electrical load in peak period when new power consumption equipment is added to old transformer area. To improve the rigid grid network (Alirezaei et al., 2015), the following technical problems must be addressed:

(1) Solve the technical problem of customer-side smart interactive energy-saving management.

With the further development of smart grid and smart power consumption, more and more attentions have been paid to the power saving via interaction between grid and customers. Without jeopardizing the normal, convenient power consumption by consumers, adopt consumer-side smart load control and management technology and encourage consumers to willingly participating in interactive power-saving management of the grid, fulfilling the purpose of ensuring load leveling, supply and demand balance, and power consumption safety.

(2) Solve the technical problem of the immense load pressure on transformers caused by simultaneous charging of a lot of electric vehicles in residential areas.
With the further popularization of electric vehicles, the number of electric vehicles in residential areas is increasing dramatically. The charging of electric vehicles, whether taking place randomly or simultaneously, brings an immense load pressure on the transformers in the residential areas. In the allowable range of the transformers, and in light of peak-valley load variation of the entire grid, the automatic control and management technology of orderly power consumption should be utilized to realize orderly charging of electric vehicles and the automatic charging in off-peak period in accordance with smart control and management principles like automatic rate adjustment mechanism, the grade of charging demand and first connected, first charged, etc., fulfilling the purpose of ensuring load leveling, supply and demand balance, and power consumption safety.

(3) Solve the technical problem of the inconsistency between the new energy power generation curve and power consumption load curve.

With the depletion of petrochemical energy, researchers are increasingly concerned with renewable energy power generation. A flexible power supply and consumption system should be built on the basis of smart grid with customer-side smart and orderly power consumption control and management technology, so that the new energy power generation curve and power consumption load curve will be in good agreement with each other, and that the rationing or overload tripping caused by imbalanced supply and demand will not happen again.

The current grid is a rigid system with poor dynamic flexibility, which is demonstrated by the rigidity for power sources and power consumption equipment to enter/exit the grid, by the fixed transmission mode of power energy, and by the absence of real-time information interaction between power consumption devices and power supply devices, and among power consumption devices. Hence, it is necessary to construct a transformer-based flexible power supply and consumption system with smart and orderly power consumption management devices and supporting smart and orderly power consumption management platform, providing the technical basis for the construction of flexible power supply and consumption system for the whole grid.

4. ARCHITECTURE OF SMART AND ORDERLY POWER CONSUMPTION MANAGEMENT PLATFORM

Based on smart and orderly power consumption devices, the smart and orderly power consumption management platform consists of the transformer station, smart and orderly consumption management device, smart and orderly consumption control and management system, controllable electrical load device, and the mobile client. The local transformer and the controllable electric load device are connected to the smart and orderly power consumption management system through a wired or wireless communication network via the smart and orderly power consumption management device (Hema and Bindu, 2014). The smart and orderly power consumption management device is responsible for orderly management of the consumer's power consumption equipment on the consumer-side (Forero et al., 2016). To be more specific, the device adjusts the orderly
operation of power consumption equipment in an automatic and flexible manner based on the load rate of the transformer and the load rate of the existing distribution network. The mobile client can be a smart phone, a pads or a third party application. It takes part in decision execution at the smart and orderly power consumption management terminal and pushes the power consumption plans at the customer-side equipment and at the customer-side (Chen, 2016). See Figure 1.

Figure 1. Architecture of Smart and Orderly Power Consumption Management Platform

As shown in Figure 1, the smart and orderly power consumption device is made up of the smart and orderly power consumption management terminal and the smart and orderly power consumption management module. The latter is further divided into the smart and orderly power consumption management module of electric vehicle charging pile, the smart and orderly power consumption management module of air-conditioners, the smart and orderly power consumption management module of new energy power generation equipment, and the smart and orderly power consumption management module of other controllable load equipment (Maehara et al., 2016). The smart and orderly power consumption management terminal is used to carry out onsite load management for consumers with a special transformer, especially the measures towards orderly power consumption like power shifting, factory shutdown, line shutdown, and the like. The smart and orderly power consumption management module of electric vehicle charging pile is used to achieve orderly management of electric vehicle charging in intelligent parks. The smart and orderly power consumption management module of air-conditioners is used to achieve orderly management of air-conditioners in intelligent parks and smart homes. The smart and orderly power consumption management module of new energy power generation equipment is used to achieve smart and orderly management of solar power, wind power and other new energies’ power generation equipment. The smart and orderly power consumption management module of other controllable load equipment is used to achieve orderly management of electric vehicles in parks, other high-power power consumption equipment in homes, etc., See Figure 2.
The communication network adapts to a variety of different networks, including wired network, wireless network, LTE network, etc. Capable of gathering and measuring power consumption information, the network provides high-speed, real-time and two-way technology support to two-way interaction of smart power consumption, consumer-side automated demand response, and smart connection of distributed power sources. In the traditional power consumption environment, the power consumption information is mainly gathered by electric power companies by collecting the watt-hour data from all metering points. In the smart power consumption environment, however, customers can participate in the load adjustment dominated by the supplier in accordance with their own generation, storage and consumption. As a power consumption information gathering and measurement network, it should be able to provide real-time and complete two-way information. In other words, the local communication network should feature high bandwidth, two-way interaction and multi-service information support. Wired or wirelessly connected to the far-end smart and orderly power consumption management system, the local communication network helps the smart, flexible and automatic adjustment of electrical load at the consumer-side according to the load curve of the distribution network, achieve economic operation of the grid and flexible load control and management, and improve the load utilization rate of power supply equipment. In this way, the network makes it possible to lower the grid operation cost and ensures the safe, reliable operation of the grid.

Figure 2. Smart and Orderly Power Consumption Management Device
5. IMPLEMENTATION MEASURES FOR SMART AND ORDERLY POWER CONSUMPTION MANAGEMENT

5.1 IMPLEMENTATION STEPS

Based on smart and orderly power consumption devices, the measures for smart and orderly power consumption management should be implemented in the following steps:

(1) The smart and orderly power consumption control and management system generates the power supply target of the current grid and the load information of the distribution network, and issues the target and information to smart and orderly power consumption management terminal via the communication network.

(2) According to the load rate of the transformer station, the smart and orderly power consumption management terminal calculates the load every 30 minutes and adjusts the power rate in light of the installed capacity of the transformer of the controllable electrical load device.

(3) Based on the main grid load, transformer load and the customer’s power consumption decision, the smart and orderly power consumption management terminal automatically sets the flexible load control plan and the real-time transformer rate. Specifically, the on-site orderly power consumption management module records the execution of the customer’s load response, the current rate, and the customer’s load information in real-time, makes feedbacks in a timely manner, adjusts the load on the spot, and uploads the information on the customer’s load and power consumption decision in real-time.

(4) The smart and orderly power consumption management terminal calculates the controllable load of the transformer and the total ratio of the controllable load, automatically generates the adjustment factor, and carries out on-site adjustment according to the controllable load and the auto-generated adjustment factor.

Through analysis, the specific processes and steps are shown in Figure 3.
The main station generates the power supply target of the current grid and issues the target to the smart and orderly power consumption management terminal.

Rate adjustment in accordance with the installed capacity of the transformer.

Smart and orderly power consumption management terminal: calculate the Controllable load of the transformer and the total ratio of the controllable load, automatically generate the adjustment factor.

On-site orderly power consumption management module: record the execution of the customer's load response, the current rate, and the customer's load information in real-time, and makes feedbacks in a timely manner.

On-site orderly power consumption management module: upload the information on the customer's load and power consumption decision in real-time.

Figures 3. Flowchart of Smart and Orderly Power Consumption Management Measures for Smart and Orderly Power Consumption Devices

5.2 OPTIMIZATION OBJECTIVE MODEL

In the optimization modeling of load management and demand response, the optimization of the power customer load is mainly aimed at minimizing the cost of the power company and the minimum User effect, the maximum of compensation. To establish the optimization model (Yao and Yuan, 2014; Guo, 2015; Xu, 2016; Huang, 2013; Liu, 2015) of the interactive planning, such as: the formula (1), the formula (2) is shown.

\[
\begin{align*}
M \sum_{t \in T} \sum_{n \in N} f(t) \Delta P(t) + \max_{t \in T} \left( c_{i}^{\text{part}} + c_{i}^{\text{shl}} + c_{i}^{\text{gip}} \right)
\end{align*}
\]

(1)
Among them, T, N, respectively, said the plan contains the number of users and periods, \( f(t) \) said the peak valley electricity price. \( C_i \) said compensation for each user, as shown in formula (3)-(5). \( U_{\Delta P_t}^{\text{trans}} \), \( U_{\Delta P_t}^{\text{shift}} \), \( U_{\Delta P_t}^{\text{clip}} \) represented the peak load translation, shifting peak and filling valley, peak clipping effect on users. \( C_{i}^{\text{trans}} \), \( C_{i}^{\text{shift}} \), \( C_{i}^{\text{clip}} \) represented the compensation paying to the user for the peak load translation, shifting peak and filling valley, peak clipping, \( \alpha_i^{\text{trans}} \), \( \beta_i^{\text{shift}} \), \( \gamma_i^{\text{clip}} \) represented the compensation for a single price, \( |\Delta t_i| \) referred to the time length of peak load translation in period of user participation, \( \Delta P_i^{\text{shift}}(t) \), \( \Delta P_i^{\text{clip}}(t) \) referred to load variation of shifting peak and peak clipping.

\[
C_{i}^{\text{trans}} = 
\left| \alpha_i^{\text{trans}} \right| \Delta t_i
\]

\[
C_{i}^{\text{shift}} = 
\beta_i^{\text{shift}} \sum_{t \in t_i} \Delta P_i^{\text{shift}}(t)
\]

\[
C_{i}^{\text{clip}} = 
\gamma_i^{\text{clip}} \sum_{t \in t_i} \Delta P_i^{\text{clip}}(t)
\]

### 6. SMART AND ORDERLY POWER CONSUMPTION MANAGEMENT TERMINAL DESIGN

#### 6.1 ORDERLY POWER HARDWARE AND SOFTWARE EXPERIMENTAL PLATFORM

Smart and Orderly Power Consumption Management terminal include hardware design and software design. For the controllable and uncontrollable (Yao and Yuan, 2014) load in the power supply range, it can implement electrical communications between electric power devices (Zheng, 2014), without affecting the user under the condition of power, and improve the ability of power supply, power information acquisition, real-time electricity price, electricity load and various strategies, realize the use of the flexible electricity, the peak electricity, the orderly electricity. Hardware experimental platform (Georigios, 2015) such as figure 4 and software experimental platform such as figure 5.
The optimal control algorithm is used to minimize the cost and minimize the difference of peak and valley the optimal target. The control object is electric equipment and the load of time interval (Umamaheswari, 2011), so the optimization objective model is:

\[
M \sum_{i=1}^{H} E P_j + MnS(\sum_{j \in T} g^{(ij)}) + \lambda (\rho_1 - \rho_2)
\]

(6)

Constraint condition:

\[
\Omega = \left\{ i \in M, j \in T \left| \rho_2 \leq \sum_{j \in T} l^i_j \leq \rho_1, 0 \leq i < H, l^\text{mn} \leq l^i_j \leq l^\text{max} \right. \right\}
\]

(7)

\( \lambda \) is the weighted factor, \( P_j \) is the total load for the user load in the whole scheduling time, \( j \) is any one device, \( i \) represents the time of load scheduling, and \( l^i_j \) is the upper and lower bounds of the load.
7. CONCLUSION

The current grid is a rigid system with poor dynamic flexibility, which is demonstrated by the absence of real-time information interaction between power consumption devices and power supply devices, and among power consumption devices. To resolve the problem, this paper comes up with a construction plan for smart and orderly power consumption management platform based on smart and orderly power consumption device. The platform aims at preventing the impact on low-voltage distribution network from the increase in power consumption equipment like electric vehicles, distributed power sources, etc. and the abrupt changes in electrical load, which undermine the reliability of the distribution network (Huang, 2015). Therefore, the author designs an orderly management of the customer’s power consumption equipment at the customer’s side, which adjusts the orderly operation of power consumption equipment in a flexible and automatic manner. For example, flexible and automatic adjustment ensures that electric vehicles will queue up orderly for charging, and the power generated from new energy sources will be absorbed locally and connected to the grid. The author’s design lowers the probability of high risk operation or collapse of the distribution network caused by blind connection of power consumption equipment in peak period, reduces the waste of power caused by the simultaneous shutdown of power consumption equipment in off-peak period, levels the load curve and improves the quality and reliability of low-voltage distribution network. As it achieves the economic operation of the grid and flexible load control, the author’s design improves the load utilization rate of power supply equipment, reduces the operation cost of grid and construction investment by the State Grid, and guarantees that the grid will run safely and reliably.

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