Research and application of non-invasive intelligent power system

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Abstract. Most of the traditional intelligent power systems collect data information through sensors installed on the user's equipment side, and then conduct intelligent operation, resulting in poor user experience. With the increase of all kinds of electrical equipment, the number of sensors to be installed is also increasing, resulting in waste of resources. It is an important direction of customer side service upgrading to build ubiquitous power Internet of things and explore a new type of intelligent power consumption mode that is customer-centric and market-oriented. Based on the requirements of the current Ubiquitous Power Internet of Things, this paper proposes a new mode of intelligent power system based on non-invasive load monitoring and identification technology. This new mode realizes diversified value-added services for power consumption, also, this mode is applied to the customization of user's personalized business, precise management and control of power equipment, so as to enhance the user's power consumption experience and build a market-oriented customer side business application has important application value.

1. Introduction

With the popularization of intelligence in various industries and the increase of the types and quantity of electric equipment, people put forward more diversified and personalized requirements for intelligent electric system [1]. At the same time, the proposal of ubiquitous power Internet of things also puts forward new standards for the construction of current intelligent power system [2]. This requires the intelligent power system to achieve efficient data processing capabilities and more intelligent user experience [3].

At present, the intelligent power consumption system is still in the invasive stage, resulting in poor user side service experience. Literature [4] analyzes the application of intelligent power consumption system in residential power saving management, but it still collects the user's power consumption information through the set of sensors. Literature [5] uses non-invasive technology to realize accident monitoring and early warning, but its function is less, and it lacks diversified intelligent application.

In this paper, the research on the user side intelligent power system is carried out, and a new intelligent power system model is proposed based on the current requirements of the ubiquitous power Internet of things; Next, it introduces the difference between invasive and non-invasive intelligent power system; Finally, it introduces the application of non-invasive intelligent power consumption system in value-added services, personalized business customization and precise control services of power equipment.
2. Overall model design of intelligent power consumption system
The intelligent power system carries out other businesses with the power as the center. The intelligent power system model proposed in this paper contains three levels of meaning, namely, the intelligent terminal of comprehensive user side information perception, the analysis center of comprehensive user side data processing, and the multidimensional application based on comprehensive perception and data processing.

The intelligent terminal realizes the comprehensive perception of information, collects the user's energy use information in real time, combines the collected data information with big data analysis, and realizes the user's energy use behavior analysis, user's abnormal power use information alarm, etc. Based on these information, multi-dimensional intelligent applications can be realized, such as: energy use analysis report to guide users to use electricity reasonably and save energy efficiency; users' abnormal power use prompt to remind users of abnormal electrical status, etc. It can also develop personalized customized business types for specific user groups, so as to form a new mode of extensive interaction and win-win cooperation between power supply enterprises and power users.

3. Working principle of noninvasive load monitoring

3.1 The difference between invasive and non-invasive
Noninvasive load monitoring was first proposed by Hart[6]. The difference between noninvasive load monitoring and intrusive load monitoring is that noninvasive load monitoring does not need to install sensors and other devices in the user's home. It only collects power consumption characteristics information through noninvasive electricity meters or terminal devices, and then analyzes load characteristics. During load characteristics matching, the purpose of monitoring is achieved. This method has low interference to users and high user experience.

3.2 Identification and analysis of non-invasive load characteristics
Noninvasive load characteristic identification deals with the collected load information such as voltage, current, power and harmonic through intelligent algorithm, then extracts different characteristic data from different loads, and then match the characteristic data, so as to achieve the purpose of load identification [7]. Figure 2 shows the waveform of different load characteristics.
In this paper, the steady-state current decomposition is used to analyze the process of noninvasive load characteristic identification. By Fourier transform the sampled current information[8], the current of the device can be expressed as:

$$i(t) = I_1(t) \cos(\omega t + \theta_1) + \cdots + I_k(t) \cos(k\omega t + \theta_k)$$  \hspace{1cm} (1)

Among them: $I_1(t)$ represents the fundamental amplitude of the load, $I_k(t)$ represents the amplitude value of the $k$ harmonic of the load; $\omega$ represents angular frequency; $\theta_1$ represents the initial phase angle of the fundamental component of the load; In order to facilitate analysis, formula (1) can be processed to obtain:

$$i'(t) = \cos(\omega t + \alpha_1) + \cdots + \alpha_k \cos(k\omega t + \theta_k)$$  \hspace{1cm} (2)

$$\alpha_k = \frac{I_k(t)}{I_1(t)}$$  \hspace{1cm} (3)

The total current formula of $n$ kinds of loads can be obtained by superposition:

$$i'_n(t) = \beta_1i'_1(t) + \beta_2i'_2(t) + \cdots + \beta_ni'_n(t)$$  \hspace{1cm} (4)

Among them: $i'_n(t)$ represents unit current of the $n$ kinds of loads; $\beta_n$ represents weight coefficient of the $n$ kinds load. Formula (4) can be expressed as:

$$\begin{bmatrix}
1\angle \theta_{1,1} \\
\vdots \\
\alpha_{k,1}\angle \theta_{k,1} \\
\vdots \\
\alpha_{m,1}\angle \theta_{m,1}
\end{bmatrix}
= 
\begin{bmatrix}
1\angle \theta_{1,1} & 1\angle \theta_{1,2} & \cdots & 1\angle \theta_{1,n} \\
\vdots & \vdots & \ddots & \vdots \\
\alpha_{k,1}\angle \theta_{k,1} & \alpha_{k,1}\angle \theta_{k,2} & \cdots & \alpha_{k,1}\angle \theta_{k,n} \\
\vdots & \vdots & \ddots & \vdots \\
\alpha_{m,1}\angle \theta_{m,1} & \alpha_{m,2}\angle \theta_{m,2} & \cdots & \alpha_{m,1}\angle \theta_{m,n}
\end{bmatrix}
\begin{bmatrix}
\beta_1 \\
\vdots \\
\beta_k \\
\vdots \\
\beta_n
\end{bmatrix}$$ \hspace{1cm} (5)

Among them: $m$ indicates the maximum harmonic number of the load; $\alpha_{k,n}$ indicates the $k$ harmonic component of class $n$ load, it can be obtained by offline or online statistics. The load can be identified by solving the weight parameter matrix $\beta$.  

![Figure 2. The waveform of different load characteristics.](image)
4. Multi dimensional application mode of intelligent power system
Thanks to ubiquitous IOT sensing terminal, non-invasive load monitoring and identification technology, combined with big data analysis and other intelligent means, intelligent power consumption system has important application value in value-added service of power users, customized service of users, precise management service of equipment.

4.1 Value added services for power users
According to the user's needs, provide the user with the energy consumption analysis report, which contains the basic information of the user's power consumption, power consumption time and standby power consumption of various types of electrical equipment. Combining the basic information, give the user's power consumption behavior habits, as the guidance for the user to save electricity. It can also provide real-time and accurate power information push services according to the needs of users, such as: common sense of power safety, etc., in order to improve the user's power experience, increase the user's stickiness, and lay the foundation for other extended services.

4.2 Customized service for power users
Different types of customers have different electricity demand and different electricity consumption behavior habits, which leads to different standards in some business types, such as: tariff package, a single form of tariff is not practical, the northern part of China entered the winter earlier, in the period before the municipal heating period, the heating equipment power consumption is large, generally difficult to distinguish with other equipment. The problem of increasing power consumption in electrification transformation and so on can be solved by personalized customized service. For example, to set different package types:

| Table 1. Package types for different electricity demand |
|---------------------------------|
| **Name of package** | **Package content** |
| Heating package | Guide customers to implement electric heating during the heating period, and give preferential policies for electricity price, such as the corresponding discount or return of electricity after the heating power consumption reaches the set power level. |
| Full electricity package | For some existing equipment that has not been electrified, the electrified transformation shall be carried out, and the electric quantity of this part shall be subsidized or preferential. |
| Family package | For the current elderly or people with mobility difficulties, business processing can be carried out by setting up family accounts and other forms. |
| Other customized packages | For office workers, student groups, people who often need to work at night, etc., multiple choice packages and time-sharing packages are provided. |

4.3 Equipment precise management service
Based on non-invasive power load monitoring and identification technology, the power consumption equipment with fault or potential safety hazard can be accurately identified in the system, and the user can be informed of these information, combined with the application of intelligent switch and other equipment, it can realize the remote power on and off of the failed electrical equipment or electrical equipment with potential safety hazards, avoid the occurrence of electric fire accidents, and achieve the purpose of precise control.

For the equipment or lines that have failed, the user can choose to apply for repair, while the intelligent power system can preliminarily draw up a repair plan according to the contents of the customer's repair application, and provide a maintenance team for the customer to choose, so as to achieve the purpose of accurate service.
5. Conclusions
Based on the requirements of the current ubiquitous power Internet of things construction, this paper proposes a new intelligent power consumption mode in view of the existing user experience and the lack of application in the current intelligent power system. Based on non-invasive load monitoring and identification technology, the mode realizes diversified value-added service of electricity consumption, and is applied to the customization of users' personalized business and precise management and control of electric equipment, comprehensively improves the user's experience of electricity consumption, enriches the diversified service application of intelligent power consumption system, and is of great significance to the in-depth mining of customer side services.

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