Development of Intelligent Electricity Data Acquisition Terminal Based on Non-intrusive Measurement Technology

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Abstract. Energy monitoring is an important part of intelligent power consumption. In the current "Coal to Electricity" work, users can not analyze the energy consumption and reasonably control the heating time. This paper studies the non-invasive measurement technology, classifies the loads, calculates the power consumption proportion of the main electrical equipment through the load monitoring algorithm. This paper analyzes and selects modules such as voltage transformer, current transformer, A/D conversion module, power module, and main computing chip. An intelligent power data acquisition terminal based on non-invasive measurement technology is developed. It not only improves the heating body feeling of residents, but also saves electricity charges for users, improves the quality of life of residents, and improves the energy utilization efficiency of terminal equipment, thus promoting the realization of national energy conservation and emission reduction strategy.

1. Introduction
With the development of "Coal to Electricity" in Tianjin, the government has formulated corresponding policy subsidies for "Coal to Electricity" users. The electricity price policy of "Coal to Electricity" issued by the National Development and Reform Commission in Binhai New Area is: ordinary electricity price of 0.49 yuan from 6:00 a.m. to 9:00 p.m., valley electricity price of 0.3 yuan from 9:00 p.m. to 6:00 a.m., and the electricity price policy is to encourage the use of heating equipment at night to enjoy preferential electricity price. Ordinary people live by heating during the day, and the demand for heating at night is relatively low. Although the government has policy subsidies for "Coal to Electricity" users, users can not analyze the energy consumption and reasonably control the heating time[1-3]. With the increasing number of electric heating users, how to improve the efficiency of electric heating and effectively guide users to use electric heating reasonably is a new service challenge faced by power enterprises[4].

2. Technical principles
The traditional measurement technology adopts the method of sub item energy consumption measurement, that is, the sub item measurement transformation of the power supply line is carried out, and the electric energy meter with communication function is installed on each type or even each equipment according to the requirements, so as to realize the data acquisition and monitoring analysis of energy consumption. Non-invasive measurement technology is a new technology of energy consumption monitoring, which does not need to enter into the load[5], only by measuring and analyzing the voltage, current and power information of the power load entrance, the real-time power
consumption ratio of different electrical equipment in the load can be obtained, so as to realize load decomposition. This technology is especially suitable for small residential users.

2.1. Load classification

According to the types and working principles of different electrical equipment, the load can be divided into air conditioning, resistance, fluorescent lamp, computer and motor. Air conditioners refer to various brands such as vertical hanging type. Resistance category refers to all kinds of electrical equipment that mainly rely on resistance heating to achieve functions, such as microwave ovens, electric heaters, etc. Fluorescent lamps refer to lighting equipment and so on. Computers include desktop computers, notebook computers and other electrical equipment with more complex features[6]. Motor category refers to equipment that mainly relies on the rotation of the motor to achieve functions, such as fans.

2.2. The fingerprint characteristics of the device type that the system can identified

We use the steady-state current harmonics of the electrical equipment as the fingerprint characteristic, which can be expressed as follows:

\[
i_a(t) = I_{a1}\cos(\omega t + \theta_{a1}) + \cdots + I_{ak}\cos(k\omega t + \theta_{ak}) + \cdots
\]

\[
I_{ak} = \alpha_{ak}I_{a1}
\]

(1)

In the formula, \(i_a(t)\) is the working current of a certain device; \(I_{a1}\) is the amplitude of the fundamental component in the current; \(\omega\) is the angular frequency of the fundamental component; \(\theta_{a1}\) is the initial phase angle of the fundamental component; \(k\) is a positive integer; \(I_{ak}\) is the amplitude of the k-th harmonic component in the current; \(k\omega\) is the angular frequency of the k-th harmonic component in the current; \(\theta_{ak}\) is the initial phase angle of the k-th harmonic component in the current; \(\alpha_{ak}\) is a proportional coefficient that represents \(I_{ak}\) and \(I_{a1}\).

After adopting the standard unit value, the above formula can become:

\[
i_a(t) = 1 \times \cos(\omega t + \theta_{a1}) + \cdots + \alpha_{ak} \times \cos(k\omega t + \theta_{ak}) + \cdots
\]

(2)

Define \(i_a(t)\) as the unit current of this type of electrical equipment, that is, the current when the amplitude of its fundamental current is 1 per unit is called the unit current of this type of electrical equipment.

In this way, using phasor description, the extracted fingerprint characteristic vector \(FP_a\) of each type of electrical equipment is:

\[
FP_a = [1, \theta_{a1}, \cdots, \alpha_{ak} \theta_{ak}, \cdots]^T
\]

(3)

2.3. Load monitoring algorithm

When the electric load contains \(n\) types of main electrical equipment (the load may also include other types of electrical equipment, but the proportion in the load current is very small and can be ignored), the current can be approximated by the linear superposition of the currents of these \(n\) types of main electrical equipment:

\[
i'_i(t) = \beta_{i1}i'_{a1}(t) + \beta_{i2}i'_{a2}(t) + \cdots + \beta_{in}i'_{an}(t)
\]

(4)

Among them, \(i'_i(t)\) represents the unit current of the electrical load, and the corresponding fingerprint characteristic vector is \(FP_{a1}, FP_{a2}\) and \(FP_{an}\); \(\beta_{i1}, \beta_{i2}, \cdots, \beta_{in}\) respectively represent the current weighting coefficients of the 1, 2, ..., \(n\) types of electrical equipment, and define \(\beta = [\beta_{1}, \beta_{2}, \cdots, \beta_{n}]^T\).

Using phasor method to describe, the above formula can be expressed as following form:

\[
FP_i = [FP_{a1}, FP_{a2}, \cdots, FP_{an}] \cdot \beta
\]

(5)
Among them, $n$ is the number of main electrical equipment types within the load. The above matrix form is also called the estimation equation system, which can be simply denoted as:

$$FP_t = H_a \cdot \beta$$

(6)

$H_a$ is called the current parameter matrix of the electric equipment unit.

Since the estimated equation system is an incompatible equation system with constraints, an optimization algorithm is selected to solve the above equation. After optimal solution, the current weight coefficients of various main electrical equipment in the power load can be obtained. After solving $\beta_1, \beta_2, \ldots, \beta_n$, the ratio coefficient of the fundamental active power and reactive power can be calculated by the following formula. The power load is decomposed according to the type of main electrical equipment.

$$\begin{align*}
\beta_{pk} &= \frac{\beta_k \cos \theta_{1ak}}{\sum_{j=1}^{n} \beta_j \cos \theta_{1aj}} \\
\beta_{qk} &= \frac{\beta_k \sin \theta_{1ak}}{\sum_{j=1}^{n} \beta_j \sin \theta_{1aj}}
\end{align*}$$

(7)

In the formula, $\beta_{pk}$ represents the ratio of fundamental active power of the k-th type of electrical equipment; $\beta_{qk}$ represents the ratio of fundamental reactive power of the k-th type of electrical equipment.

Through the above analysis, the flow of the load monitoring algorithm is as follows:

According to the actual power load, select the main electrical equipment (air conditioner, resistor, fluorescent lamp, computer, motor, etc.). Form the current parameter matrix of the electrical equipment unit. Perform harmonic analysis on the steady-state data of the measured power load voltage and current to form the load port current column vector. Form a constrained estimation equation set. Apply a suitable solution algorithm to calculate the estimated equations to obtain the current weight coefficient. According to the definition of power, find the power consumption ratio of each main electrical equipment.

3. Development of data collection terminal

The data acquisition terminal is to collect the required current signal, voltage signal and perform data analysis to send the data to the concentrator. This article analyzes the voltage transformer, current transformer, A/D conversion module, power supply module, main calculation chip and other modules respectively.

3.1. Voltage transformer

The function of the voltage transformer is to collect the voltage value of the sampling point. We have compared the semi-closed voltage transformer and the fully enclosed voltage transformer. The fully enclosed voltage transformer encapsulates the coil and the iron core, which is more beautiful and requires no maintenance, and the risk of interference is lower. Therefore, we choose a fully enclosed voltage transformer.

3.2. Current transformer

The function of the current transformer is to collect the current value of the sampling point. The current signal collected by the equipment mainly relies on the current transformer. We compared the open current transformer and the closed current transformer, and found that open current transformer has low sampling accuracy and large error. The closed current transformer has high sampling accuracy and low error, so we choose closed current transformer.

3.3. A/D conversion module

The function of the A/D conversion module is to perform A/D conversion on the collected data. This paper have compared four types of A/D converters: integral type, successive comparison type, parallel
comparison type and serial parallel comparison type. The successive comparison A/D converter is composed of a comparator and D/A converter through successive comparison logic. Starting from the MSB, sequentially compare the input voltage with the output of the built-in D/A converter for each bit, and output the digital value after \( n \) comparisons. The circuit scale is medium. Its advantages are high speed, low power consumption, low price at low resolution (less than 12 digits), but high price at high precision (more than 12 digits). Considering the accuracy and price, we choose the successive comparison type A/D converter.

3.4. Power module
The function of the power supply is to ensure the power supply of the equipment itself. Power supply capacity should consider the power consumption of the equipment sampling part, the power consumption of the core components, the power consumption of the communication module, etc. In order to ensure the safe and stable operation of the equipment, we compared three power modules: power transformer, switching power supply and linear power supply. Among them, the switching power supply has the advantages of small size and good reliability. Considering the limited installation space, the product needs to be connected to the network for a long time, and it must have high reliability requirements, so we choose the switching power supply.

3.5. Main computing chip
The function of the main computing chip is to calculate the total power and decompose the load at the same time. The main computing chip should meet the calculation requirements of large data volume and high frequency. At the same time, considering that the power consumption of the equipment is limited, it cannot exceed the power consumption of the original traditional electric meter. Therefore, products with strong computing power, low power consumption and high versatility should be selected. We compared four main computing chips: FPGA, DSP, AVR and ARM. Taking into account the needs of computing processing, communication, cost, etc., ARM chip is used as the main computing chip.

4. Application effectiveness
The intelligent electricity data collection terminal based on non-intrusive measurement technology developed by us has been piloted in Binhai Power Supply Branch of State Grid Tianjin Electric Power Company, and has achieved certain economic and social benefits.

4.1. Economic benefits
Resident users can understand the total energy consumption of the household in all aspects, and users can grasp the true cost-effectiveness ratio. After considering government subsidies and overall heating, users try to increase the heating time by 4 hours per day (2 hours peak and 2 hours valley). Coal-to-electricity users (4217 households in this renovation) have developed this electricity consumption pattern and can achieve an increase of 10 million in electricity and 3.98 million in electricity bills during the heating season. Users have invested 940 yuan per household in the new cost of improving the heating and feeling, and the government subsidy calculation during the comprehensive heating season, users can still have a balance of about 650 yuan after the improvement of the body feeling. At the same time, it can realize the wide application of distributed energy, realize the access of regional green energy, and combine the household electricity to shift the peak and fill the valley, which will greatly save the infrastructure investment of the power plant and the power grid.

4.2. Social benefits
It can realize the two-way information interaction between the power grid and users and the application of smart home appliances, so that residents can understand the total energy consumption of the household in all aspects. Encourage users to use energy rationally and green energy, which is conducive to improving the energy efficiency of terminal equipment and reducing the consumption of
the whole society. That can promote the realization of the national energy conservation and emission reduction strategy. At the same time, it can provide users with more convenient, high-quality and efficient services, which greatly meets the diversified needs of residents and improves the quality of life of residents.

5. Conclusion
In view of the problem that users cannot analyze the energy consumption and reasonably control the heating time in the current "Coal to Electricity" work, we have conducted research on non-intrusive measurement technology and calculated the electrical energy of major electrical equipment through load monitoring algorithms. We have analyzed and selected modules such as voltage transformer, current transformer, A/D conversion module, power supply module, main calculation chip, etc, and developed an intelligent electricity data collection terminal based on non-intrusive measurement technology. We applied the terminal on a pilot basis in the Binhai Power Supply Branch of State Grid Tianjin Electric Power Company, and achieved certain economic and social benefits, which not only improved the heating experience of residents, but also saved users’ electricity bills and improved residents’ lives. The quality of life improves the energy efficiency of terminal equipment, thereby promoting the realization of the national energy-saving and emission-reduction strategy.

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