Resident Load Influence Analysis Method for Price Based on Non-intrusive Load Monitoring and Decomposition Data

Wenqian Jiang*, Bo Zeng, Zhou Yang, Gang Li

Guangxi Power Grid Electric Power Research Institute, Nanning, China;

*Corresponding author e-mail: jwqqsky@126.com

Abstract. In the non-invasive load monitoring mode, the load decomposition can reflect the running state of each load, which will help the user reduce unnecessary energy costs. With the demand side management measures of time of using price, a resident load influence analysis method for time of using price (TOU) based on non-intrusive load monitoring data are proposed in the paper. Relying on the current signal of the resident load classification, the user equipment type, and different time series of self-elasticity and cross-elasticity of the situation could be obtained. Through the actual household load data test with the impact of TOU, part of the equipment will be transferred to the working hours, and users in the peak price of electricity has been reduced, and in the electricity at the time of the increase Electrical equipment, with a certain regularity.

1. Introduction

With the development of the national economy, electric power play more important position in daily life. The demand side management becoming increasingly prominent, time of using price (TOU) and other measures have been guided low-voltage user consumption process and effectively improved energy efficiency [1]. More detailed user-side data and the user characteristics analysis are required.

Some relevant literatures on the electricity consumption of the user response characteristics and analysis methods were studied. In ref. [2], the different types of power load are analyzed, and the demand response load curve of the user after the time of using price is obtained. According to the principle of economics, the demand response behavior of users under the time-sharing price environment is analyzed. In ref. [3], real response curve of the user considering electricity price is put forward, and the real-time simulation process with user demand response behavior under the price for peak-valley time is given. The operation characteristics and the power supply cost of power system are analyzed in [4], which provided the marginal electricity cost model for power system and the load rate sub-cost and two-part pricing theory. However, the above methods are mainly based on the overall characteristics of the user, not deep into the user content device level.

As traditional method uses the intrusion design, the sensor and electricity information gathering equipment are installed to obtain the related information. When the power equipment is more, huge amount of collection device and high installation cost are need. The non-intrusive load monitoring and decomposition (NILMD) for low-voltage user is proposed and widely concerned with the traditional approach to intrusion [5], which can analyze the monitoring area of electricity equipment consumption with high frequency detailed information [6].

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In the non-invasive load monitoring mode, the running state of each load can intuitively and completely reflect with load decomposition. In this paper, a resident load influence analysis method for TOU price based on non-intrusive load monitoring data are proposed. Based on the current signal of the residents' load, the user equipment type, the self-elasticity and cross-elasticity coefficient of different time series are obtained. Then the demand side management measures, such as time of using price, could be designed, which will change the user consumption to reduce the safe operation risk of the distribution network.

2. Non-invasive load monitoring and signal decomposition principle

2.1. Non-invasive load monitoring principle and signal model

Non-invasive load monitoring only at the power entrance to the current, voltage and power and other information collection, through the analysis of these electricity information, the operation of the load within the electricity network could be analysed. Load identification is an indispensable part of non-invasive load monitoring, and is a more effective way to identify by load signal decomposition. According to the characteristics of household power load, such as voltage, current, active power, reactive power, the characteristics of the load extraction, and then extract the load characteristics of the analysis to achieve load decomposition. Although this method can achieve the purpose of decomposition, but the need for the characteristics of the cumbersome feature extraction and analysis, and the lack of load signal on the overall analysis [7].

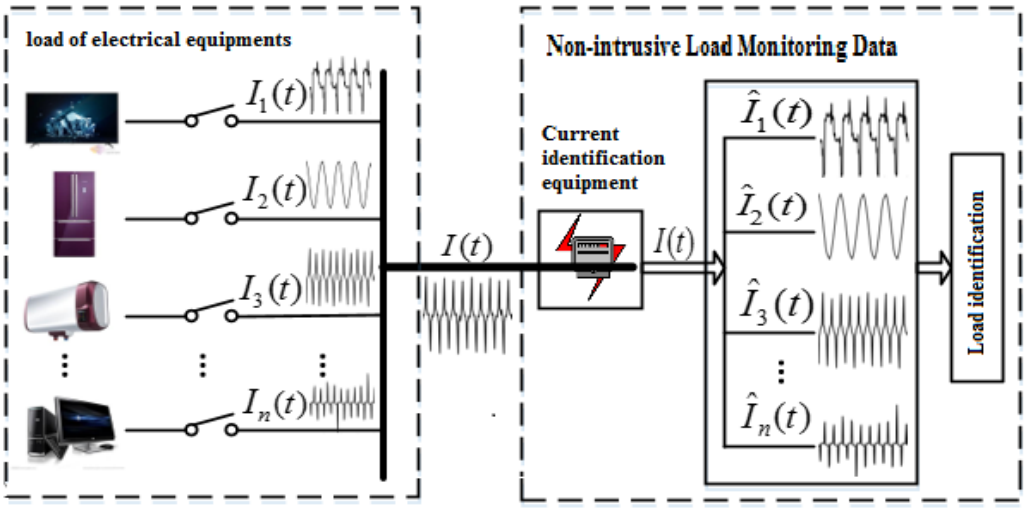

Figure 1. System diagram of power load signal decomposition

In practice, there are usually lots of electricity loads co-put into operation, due to the load is running with uncertainty, the total current signal is the load current signal of the random linear mixing. Figure 1 shows a total of n load of electrical equipment in user network, the current signal of each load branch is Ii(t), where i is the number of each load, and i = 1, 2, ..., n. The total current I(t) is a current signal which is mixed with the current signal flowing into the respective load branches and contains the current signals of the respective electric loads. Therefore, if the original independent of the mixed current is decomposed from the mixed total current signal according to the signal characteristics Îj(t) are the currents of the independent loads recovered from the mixed signal, and the load can be effectively realized by the load of the current signal, so that the load can be effectively realized. Signal, where j is the number of the recovery signal.

2.2. Statistical independence of load current signals

The number of family load the number of different orders, including a few less electrical equipment, and some users of the family contains dozens of electrical equipment, as long as the load of different current signals to meet the statistical independence between each other. As the number of loads increases, the time required for non-invasive load decomposition and impact analysis operations will increase slightly, but the overall time required is still short.

According to the input and output system relationship analysis, each load can be regarded as a separate system, its time domain representation as hi(t); grid side voltage U(t) is the input excitation signal; when the load is running separately, the current signal Ii(t) is the output signal. The parameters are converted to the frequency domain, the output current signal can be obtained and the relationship between the input excitation:

$$I_i(\mathrm{j}\omega) = U(\mathrm{j}\omega)H_i(\mathrm{j}\omega) \tag{1}$$

Where $I_i(\mathrm{j}\omega)$, $U(\mathrm{j}\omega)$ and $H_i(\mathrm{j}\omega)$ are the output current Ii (t), the input voltage U (t) and the load system hi (t) of the Fourier transform.

2.3. Load decomposition algorithm implementation process

The current signal Ii (t)) is the source signal of the algorithm, n is the number of electricity load. The frequency domain representation of the current signal Ii (t) is shown in equation (2).

$$I_i(\mathrm{j}\omega) = \sum_i^n I_i(t)e^{-\mathrm{j}\omega t} \tag{2}$$

Where, $I_i(\mathrm{j}\omega)$ for the load independent operation of the current signal spectrum. To avoid the impact of the current signal dimension, to normalize it, get the normalized spectrum recorded $I_{i-norm}(\mathrm{j}\omega)$.

$$I_{i-norm}(\mathrm{j}\omega) = \frac{I_i(\mathrm{j}\omega)}{\max(|I_i(\mathrm{j}\omega)|)} \tag{3}$$

According to the actual operation model, the mixed current signal collected under non-invasive monitoring is linear superposition of the current signal at different load independent operation, and the mixed current is recorded as the observation signal I(t), that is,

$$I(t) = \sum_i^n \lambda_i I_i(t), \quad i = 1,2,...,n \tag{4}$$

Where, λi is the linear weighting factor for each load branch. Considering the actual line loss and noise on the impact of different branches, the weight coefficient should be selected (0, 1) between the random number.

3. Electricity users' response to electricity price and electricity transfer function

3.1. Reduction and translation of load characteristics

For rational users, the implementation of time of using price before and after the peak hours of electricity can be described as follow [3].

$$d_{\mathrm{fEXE}} = d_{\mathrm{fNON}} - \Delta d_{\mathrm{fEXE}} \tag{5}$$

Where, dfEXE for the implementation of time of using prices after peak hours of electricity demand; dfNON for the implementation of time of using electricity before the peak hours of electricity demand; $\Delta d_{\mathrm{fEXE}} = \Delta d_{\mathrm{ftrans}} + \Delta d_{\mathrm{fsave}}$ for the implementation of time of using price changes after the peak demand; Δdftrans for real time Electricity demand caused by the demand for electricity transfer; Δdfsave for users in the peak hours of reduced demand for electricity.

Time of using price environment, there are two types of load will be cut at the peak time, the first category for the actual load savings; the second category for the peak period of the increase in electricity consumption generated by other periods of load increase. Using λfsave to describe the user in the peak hours to reduce the amount of electricity and the implementation of time of using electricity before the peak hours of electricity ratio.

$$\lambda_{\mathrm{fsave}} = d_{\mathrm{fsave}} / d_{\mathrm{fNON}} \tag{6}$$

The second type of load users in the peak time period to the normal period and the trough of the electricity were expressed by Δd_{fp} and Δd_{fg}, then the user in the peak period of time to transfer to other times the ratio of electricity consumption λftrans, that is:

$$\lambda_{\mathrm{ftrans}} = \lambda_{\mathrm{fp}} + \lambda_{\mathrm{fg}} = \frac{\Delta d_{\mathrm{fp}}}{d_{\mathrm{fNON}}} + \frac{\Delta d_{\mathrm{fg}}}{d_{\mathrm{fNON}}} \tag{7}$$

Where λfp and λfg are the ratio of the user load to the peak period and the valley period during the peak period, respectively. The first type of load is the special case of the second type of load, and its λfp and λfg values are zero. Through the analysis of different types of load can be obtained to reflect a certain type of load of electricity characteristics, and then get the implementation of time of using price of the user's demand response load curve.

3.2. Multiperiod load reduction and transfer model

For the second type of load, during peak periods, the amount of electricity consumed by the load reduction includes the reduction of the electricity price due to the increase in electricity prices, as well as the delayed or early use of the part, the latter's electricity will be translated to other periods, this time involved in different the elasticity of the period. The elasticity between the load of the same user in the i period and the price of the j period can be defined as:

$$E_l(i,j) = \frac{d_l(i) - d_{l,0}(i)}{\rho(j) - \rho_0(j)} \times \frac{\rho_0(j)}{d_{l,0}(i)} \tag{8}$$

When i = j, called self-elasticity, describing the change in demand within a time interval relative to the price change in the same time interval, this is E(i). When $i \neq j$, it is called cross elasticity and describes the change in demand within a time interval relative to the price change over another time interval. In general, the load demand is inversely proportional to the price in the same period, which is proportional to the price of other periods. In general, El (i, i) ≤0, when $i \neq j$, then El (i, j) ≥0.

If 24 hours for a cycle, the first stage of the load for TOU changes can be expressed as:

$$d_l(i) = d_{l,0}(i) + \sum_{j=1}^{24} \left\{ E_l(i,j) \times \frac{d_{l,0}(i)}{\rho_0(j)} \times \left[\rho(j) - \rho_0(j) \right] \right\} \tag{9}$$

Let λl(i) denote the change rate of electricity consumption of user l in stage i due to the implementation of TOU, there are

$$\lambda_l(i)=\frac{d_l(i)-d_{l,0}(i)}{d_{l,0}(i)}=\sum_{j=1}^{24}\left\{E_l(i,j)\frac{\left[\rho(j)-\rho_0(j)\right]}{\rho_0(j)}\right\} \tag{10}$$

If the electricity price ρ0 (j) before the time of using price is expressed by the express price, the peak-to-peak price is the part of the peak-to-hour electricity price. The price difference between the peak and valley price of the electricity price.

4. Mathematical analysis

In order to illustrate the application effect of proposed algorithm in the non-invasive decomposition of residential electricity load, this paper chooses the typical family as the research object and validates the measured data of the resident load obtained by non-invasive acquisition mode.

Select a typical resident load, and a full range, covering the resistance type, motor type and switching power supply and other types. Since the load is switched between on and off, the number of loads that need to be decomposed will change. Figure 2 shows the current part of the load when the current signal flow time domain waveform, it can be seen from the figure, the selected load current signal waveforms are different from each other, including the implementation of electricity management on the user comfort greater impact TV, electric lights, etc. Through the time shift to optimize the use of water heater, washing machine, rice cooker load, and by adjusting the gear to achieve power changes in the fan, air conditioning and so on. Electric vehicle can be used before any time to charge, usually choose the lower price of electricity to charge, even in the higher price of electricity at the time of discharge, and will not affect the user's comfort.

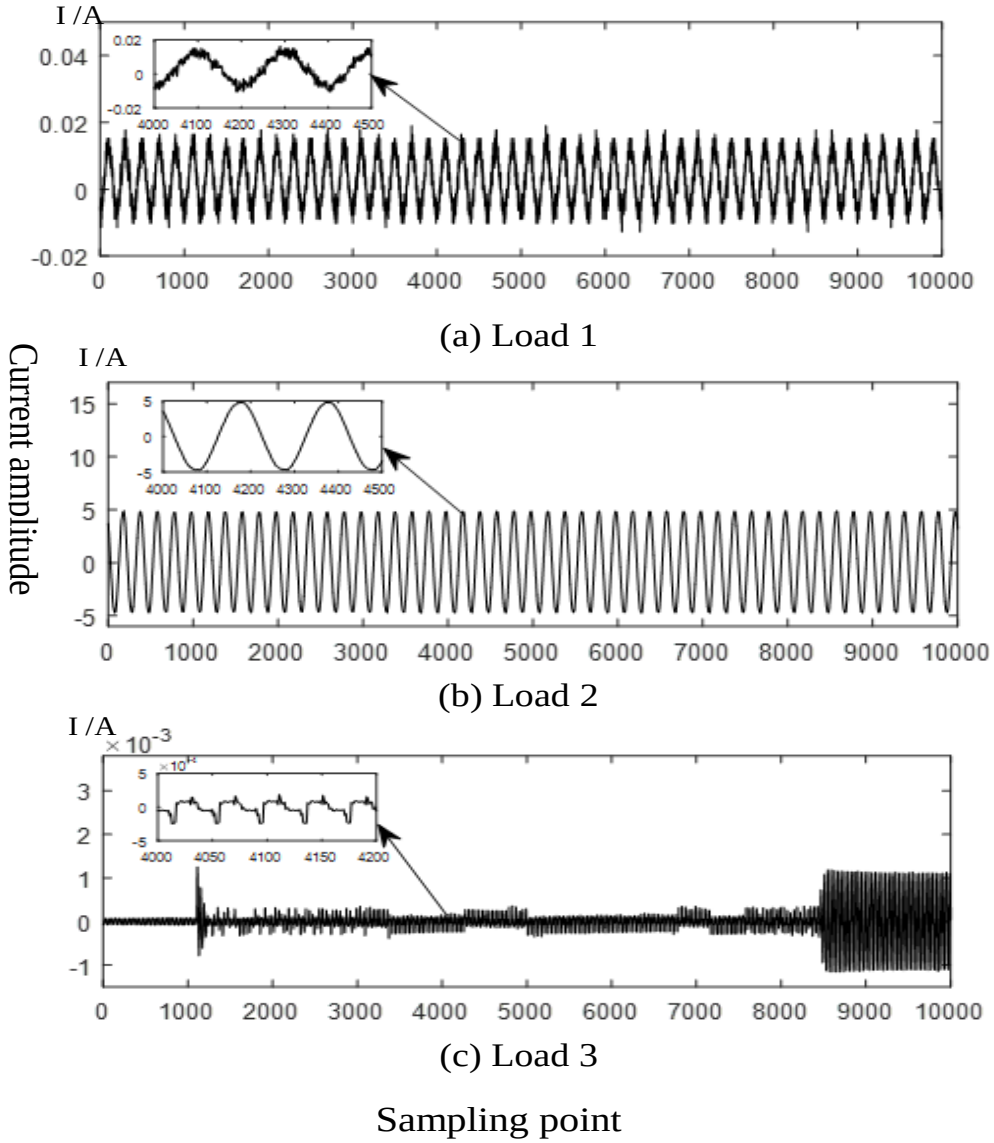

Figure 2. Current signals of the five power loads

Based on non-invasive technology, different time of using tariffs can be decomposed on different types of loads based on current signals. Through a long time to determine the analysis, the price changes in the case of the user's load type components and power characteristics can be observed.

As user have different power habits and for a variety of equipment operating parameters set different, different power equipment to play the role is different. Such as electric cars, in the working day, due to the need to use the next day, it must be completed in the morning before the completion of the charging task, this time as an electric vehicle to participate in household load planning; in the weekend, the electric vehicle did not travel the next day, and the task can be used as energy storage in the family load planning.

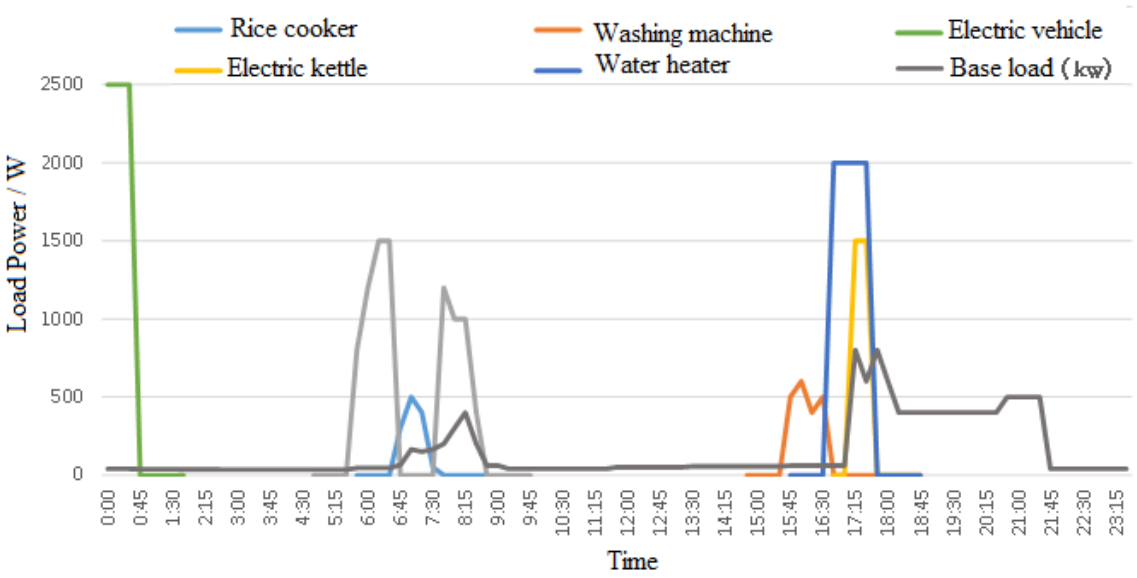

Figure 3. Workday home load optimization results.

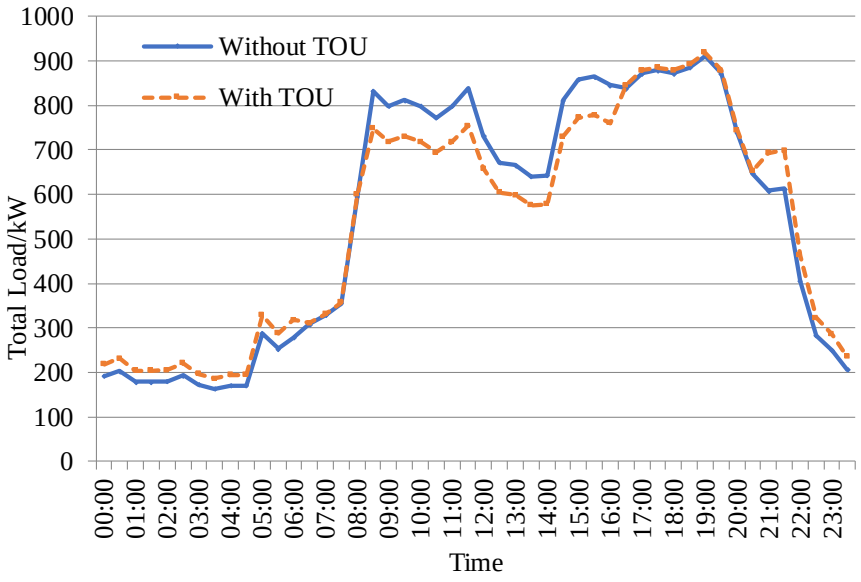

Figure 4. Total load change with/without TOU.

As can be seen from Figure 3, the working time of the equipment is shifted, and the maximum peak of the household load is shifted from the peak period of the optimization to the usual period. Through the calculation we can see that you can reduce the cost of electricity more than 20%, indicating that the optimization algorithm for the user to save electricity costs effect is very significant. The total load variation curve before and after the time of using price is shown in Figure 4. It can be seen from the figure that the total load is reduced in the peak hours of the electricity price, and the load is mostly reduced for the washing machine and air conditioner. Electric cars and water heaters have increased the proportion of electricity, with a certain regularity. As the user to take the initiative to respond to demand, but also smooth the load curve, reducing the peak time power grid company power backup pressure.

5. Conclusion

Based on the non-invasive data of households, the current signal decomposition method of resident load based on the demand side management measures such as TOU was studied. With the self-elasticity and cross elasticity coefficient of different time series, to obtain the user to implement the demand-side management based on the price of the load after the change. According to the typical household electricity load data, the user will consider the working hours of some of the equipment, and the total load will decrease in the peak time of the electricity price.

Acknowledgments

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