

SPECIFICATION

A Non-intrusive Induction Heating (IH) Electric Cooker Operating Identification Method Based on Hybrid Criteria

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Technical Field

The present invention belongs to the technical field of intelligent power consumption, and relates to a non-intrusive induction heating (IH) electric cooker operating identification method based on hybrid criteria.

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Background

Residential power load monitoring and decomposition technology is an emerging basic supporting technology for smart grids. Different from the current smart meters which only measure the total power of users, it aims at monitoring and decomposing the starting time, working state and energy consumption of all appliances in a household, thus achieving more reliable and accurate electric energy management. The electric power load monitoring and decomposition technology makes the user's electricity charge list like a cellphone charge list, the electricity consumption of various household appliances are clear at a glance, so that the user knows his electric power consumption in time, providing a reference for the reasonable distribution of the electricity consumption time and the corresponding electricity consumption of each appliance. Finally, the money spent on electricity and electric energy waste can be effectively reduced. Statistical data from *Google* shows that the monthly electric charge can be reduced by 5%~15% if home users can get the detailed information on electricity consumption of residential electric appliances in time. If half of all U.S. households save so much money every month, the reduction in carbon emissions is equivalent to reduction of 8 million cars. For industrial users, the load switching arrangement is generally fixed, which only requires time-division measurement, with less demand for load decomposition, and the main research object of this project is the residential electricity consumption load.

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Currently, the residential power load monitoring and decomposition technology is mainly divided into two categories: *intrusive load monitoring and decomposition (ILMD)* and *non-intrusive load monitoring and decomposition (NILMD)*:

(1) *Intrusive load monitoring and decomposition (ILMD)*: Sensors with the digital communication function are installed at the interface between each electric appliance and the power grid by intrusive load monitoring to allow accurate monitoring of the operating state and power consumption of each load. However, the cost for construction and maintenance is high due to the installation of a large number of monitoring sensors. Above all, the intrusive load monitoring requires installation and debugging in residents' homes, which easily results in the users' emotional resistance.

(2) *Non-intrusive load monitoring and decomposition (NILMD)*: A sensor is installed only at the user's entry to judge the power consumption and working state (for example, the air conditioner has different working states such as refrigeration, heating and standby) of each or each type of electric appliance in the house by collecting and analyzing the total current, voltage and other information at the entry, thus arriving at the law of the resident's electricity consumption. Since only one monitoring sensor is to be installed, both the construction cost and the difficulty of maintenance in the later period of the non-intrusive load decomposition scheme are greatly reduced compared with the intrusive load decomposition; in addition, the sensors are selectively installed at the user's meter box without invading into the household for construction at all. It can be considered that *NILMD* using the decomposition algorithm instead of the sensor network of the *ILMD* system has the advantages of simplicity, economy, reliability, data integrity and easy and fast popularization and application. It is expected to develop into a new generation of core technology in the Advanced Metering Infrastructure (*AMI*) (after it becomes mature, the *NILMD* algorithm can also be integrated into smart meter chips) and support the demand side management, custom power and other advanced functions of intelligent power consumption, and it also applies to the temporary monitoring and investigation of load power consumption details.

The heating principle of the *IH* electric cooker is electromagnetic heating, so it is quite different from the traditional electric cooker using the heating principle of an electric heating plate in terms of electrical characteristics. The investigation and survey show that the operation process of the *IH* electric cooker is also accompanied by reactive changes in addition to the characteristics of intermittent operation. Therefore, the existing non-intrusive load identification algorithm for identifying electric cookers is no longer applicable to the identification of the *IH* electric cooker.

To sum up, *NILMD* technology has gradually become a research focus, and the breakthrough and industrialization of related technologies are of great significance to the energy conservation and emission reduction of the whole society. At present, the research of *NILMD* technology is still in the stage of

theoretical research, and the algorithm of effectively distinguishing a percussion drill from a constant-frequency air conditioner has yet to be broken through.

Therefore, a non-intrusive induction heating (IH) electric cooker operating identification method is needed to solve the above problems.

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Summary of the Invention

The present invention aims at solving the problem by providing a non-intrusive induction heating (IH) electric cooker operating identification method based on hybrid criteria.

The present invention achieves the above purpose through the following technical scheme:

10 A non-intrusive induction heating (IH) electric cooker operating identification method based on hybrid criteria, comprising the following steps:

1). acquiring current waveform data $u(t)$ and voltage waveform data $i(t)$ at a main incoming line at the sampling frequency f , wherein, $t=t_0+1, t_0+2, \dots, t_0+N$, t_0 is the current and voltage sampling sequence number, and calculating an average active power sequence $P(t)$ and an average inactive power sequence $Q(t)$;

2). calculating an active power change ΔP_{on} and an inactive power change ΔQ_{on} during switching-on, and an active power change ΔP_{off} and an inactive power change ΔQ_{off} during switching-off;

3). matching the adjacent starting and stopping of a load, when the following formula is satisfied,

$$|\Delta P_{on} + \Delta P_{off}| < \delta P$$

$$|\Delta Q_{on} + \Delta Q_{off}| < \delta Q$$

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where δP and δQ are the matching errors of active power and reactive power, respectively; go to Step 4), otherwise go to Step 2);

4). counting a load operation time interval Δt_{on} , a stopping time interval Δt_{off} and a temperature control time interval Δt_{ctr} , and counting the accumulated number of operation times M of the load for a continuously occurring duty cycle k , wherein, the duty cycle $k = \Delta t_{on} / \Delta t_{off}$ for operations of the load;

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5). if $P_1 < \Delta P_{on} < P_2$, $M > M_0$, $Q_1 < \Delta Q_{on} < Q_2$ and $T_1 < \Delta t_{ctr} < T_2$, it is judged as the IH electric cooker, wherein, P_1 and P_2 are the minimum and maximum of the active power change of the IH electric cooker, M_0 is the minimum accumulated number of operation times of the IH electric cooker for a continuously

occurring duty cycle k , Q_1 and Q_2 are the minimum and maximum of reactive power change of the IH electric cooker, T_1 and T_2 are the minimum and maximum of the temperature control interval of the IH electric cooker.

Further, the range of sampling frequency f in Step 1) is $0.5kHz \sim 2kHz$.

- 5 Further, the average active power sequence $P(t)$ and the average reactive power sequence $Q(t)$ in Step 1) are calculated by the following formula:

$$P(t) = |U|_0 * |I|_0 * \cos(\Delta\varphi)$$

$$Q(t) = |U|_0 * |I|_0 * \sin(\Delta\varphi)$$

where

$$|U|_0 = \frac{2\sqrt{U_x^2 + U_y^2}}{N}$$

$$|I|_0 = \frac{2\sqrt{I_x^2 + I_y^2}}{N}$$

$$\Delta\varphi = \arctan\left(\frac{U_y}{U_x}\right) - \arctan\left(\frac{I_y}{I_x}\right)$$

- 10 N is the number of points of FFT analysis,

$$U_N = FFT(u(t))$$

$$I_N = FFT(i(t))$$

- wherein, $t=t_0+1, t_0+2, \dots, t_0+N$, t_0 is the current and voltage sampling sequence number, N is the number of points for fast Fourier transformation, t is the time point, FFT is the fast Fourier transformation function, N complex points are obtained after fast Fourier transformation of N points, then the frequency represented by the n th point is $f_n=f*n/N$, wherein, $n=0, 1, 2, \dots, N-1$, the 0th point represents the DC component, the fundamental wave is calculated as per $n_0=N*f_0/f$, for the complex sequences U_N and I_N , the complex number corresponding to the point n_0 of the fundamental wave is recorded as follows:

$$U_N(n_0) = U_x + jU_y$$

$$I_N(n_0) = I_x + jI_y$$

wherein, j is a complex unit.

- 20 Further, N is the integer power of 2.

Further, the active power change ΔP_{on} and the inactive power change ΔQ_{on} and the active power change ΔP_{off} and the inactive power change ΔQ_{off} during switching-off in Step 2) are obtained by the following formula:

$$\Delta P_{on} = P(t_s + \Delta t_s) - P(t_s)$$

$$\Delta Q_{on} = Q(t_s + \Delta t_s) - Q(t_s)$$

$$\Delta P_{off} = P(t_e) - P(t_e - \Delta t_e)$$

$$\Delta Q_{off} = Q(t_e) - Q(t_e - \Delta t_e)$$

5 wherein, t_s and t_e are for the rise step time and fall step time respectively, representing the on time and off time of a load, Δt_s and Δt_e represent the minimum time interval of the active sequence point and the minimum time interval of the reactive sequence point respectively.

Further, the operation time of the IH electric cooker in Step 3) comprises the operation time interval Δt_{on} , the stopping time interval Δt_{off} and the temperature control time interval Δt_{ctr} , wherein, $\Delta t_{ctr} > 2 * \Delta t_{off}$,

The temperature control time interval Δt_{ctr} is screened according to the above formula.

According to the heating principle of the IH electric cooker, the IH electric cooker is always in circular operation in the way of "heating - insulation", the heating process is to control the actual operation power of the electric cooker with the short-term operation time interval Δt_{on} and the stopping time interval Δt_{off} , the insulation process is a long-term operation stopping process after the heating process is ended, and the time recorded at the temperature control time interval Δt_{ctr} is the duration of the operation stopping process.

The present invention has the advantages that: the non-intrusive induction heating (IH) electric cooker operating identification method based on hybrid criteria of the present invention combines the hybrid criteria of the intermittent operation characteristic (number of times of intermittent operation N and temperature control time characteristic Δt_{ctr}), electromagnetic heating characteristic (reactive power change ΔQ) and power consumption characteristic (active power change ΔP) of the IH electric cooker, the IH electric cooker can be effectively identified, and the precision of identification is improved.

Brief Description of the Drawings

FIG.1 is the algorithm flow chart of the non-intrusive induction heating (IH) electric cooker operating identification method based on hybrid criteria;

FIG.2 is the active and reactive waveform graph of the non-intrusive induction heating (IH) electric cooker operating identification method based on hybrid criteria;

FIG.3 is the calculation process diagram of the non-intrusive induction heating (IH) electric cooker operating identification method based on hybrid criteria.

Detailed Description of the Preferred Embodiments

The technical schemes in the embodiments of the present invention will be illustrated clearly and completely below in combination with the accompanying drawings in the embodiments of the present invention. Apparently, the described embodiments are merely some of the embodiments of the present invention, not all of them. Based on the embodiments in the present invention, all other embodiments obtained by those of ordinary skill in the art without any creative effort belong to the scope of protection of the present invention.

As shown in FIG.1, FIG.2 and FIG.3, according to the non-intrusive induction heating (IH) electric cooker operating identification method based on hybrid criteria of the present invention, the reactive power is translated downward 100Var as a whole in order to display both the active power and the reactive power obviously on the same diagram, and the specific process steps are as follows:

(1) In FIG.2, taking a total of 512 points in the first 4 cycles of 5 cycles for fast Fourier transformation with the sampling frequency $f=6400\text{Hz}$, then calculating the average power sequence P and the second harmonic sequence im , and then the result is an average active power point and a reactive power point in 0.1 second.

(2) In FIG.3, given $\delta P=20\text{W}$, $\delta Q=5\text{Var}$, for the first starting and stopping state, there are

$$\Delta P_{on}=P(t_s+\Delta t)-P(t_s)=1188-0.3721=1187.63 \text{ (W)}$$

$$\Delta Q_{on}=Q(t_s+\Delta t)-Q(t_s)=-155.6-(-95.1)=-60.5 \text{ (Var)}$$

$$\Delta P_{off}=P(t_e+\Delta t)-P(t_e)=1.761-1197=-1195.24 \text{ (W)}$$

$$\Delta Q_{off}=Q(t_e+\Delta t)-Q(t_e)=-98.79-(-156.3)=57.51 \text{ (Var)}$$

then

$$|\Delta P_{on} + \Delta P_{off}| = 7.61 < \delta P$$

$$|\Delta Q_{on} + \Delta Q_{off}| < 2.99 \delta Q$$

This is a complete start-stop process. The same calculation is conducted for subsequent start-stop processes. At the same time, the starting and stopping times are recorded, and the time of the first start-stop process is calculated as per $\Delta t_{on} = 6.8 - 4.3 = 3.5$ (s), $\Delta t_{off} = 7.5 - 6.8 = 0.7$ (s) and $k = 3.5 / 0.7 = 5$, there are
5 totally 8 complete start-stop processes with the duty cycle $k=5$, the first temperature control time interval is $\Delta t_{ctr} = 58.4 - 31.8 = 26.6$ (s), the given thresholds are $M_0 = 3$, $P_1 = 1100$ (W), $P_2 = 1200$ (W), $Q_1 = -65$ (Var), $Q_2 = -55$ (Var), $T_1 = 10$ (s) and $T_2 = 50$ (s), and it is known that the calculations above meet the judging conditions

$$P_1 < \Delta P_{on} < P_2, M > M_0, Q_1 < \Delta Q_{on} < Q_2, T_1 < \Delta t_{ctr} < T_2$$

10 Thus, it is judged that the *IH* electric cooker operates from 4.3 seconds to 58.4 seconds.

CLAIMS

1. A non-intrusive induction heating (IH) electric cooker operating identification method based on hybrid criteria, characterized by comprising the following steps:

5 1). acquiring current waveform data $u(t)$ and voltage waveform data $i(t)$ at a main incoming line at the sampling frequency f , wherein, $t=t_0+1, t_0+2, \dots, t_0+N$, t_0 is the current and voltage sampling sequence number, and calculating an average active power sequence $P(t)$ and an average inactive power sequence $Q(t)$;

2). calculating an active power change ΔP_{on} and an inactive power change ΔQ_{on} during
10 switching-on, and an active power change ΔP_{off} and an inactive power change ΔQ_{off} during switching-off;

3). matching the adjacent starting and stopping of a load, when the following formula is satisfied,

$$\begin{aligned} |\Delta P_{on} + \Delta P_{off}| &< \delta P \\ |\Delta Q_{on} + \Delta Q_{off}| &< \delta Q \end{aligned}$$

where δP and δQ are the matching errors of active power and reactive power, respectively; go to Step

15 4), otherwise go to Step 2);

4). counting a load operation time interval Δt_{on} , a stopping time interval Δt_{off} and a temperature control time interval Δt_{ctr} , and counting the accumulated number of operation times M of the load for a continuously occurring duty cycle k , wherein, the duty cycle $k = \Delta t_{on} / \Delta t_{off}$ for operations of the load;

5). if $P_1 < \Delta P_{on} < P_2$, $M > M_0$, $Q_1 < \Delta Q_{on} < Q_2$ and $T_1 < \Delta t_{ctr} < T_2$, it is judged as the *IH* electric cooker,
20 wherein, P_1 and P_2 are the minimum and maximum of the active power change of the *IH* electric cooker, M_0 is the minimum accumulated number of operation times of the *IH* electric cooker for a continuously occurring duty cycle k , Q_1 and Q_2 are the minimum and maximum of reactive power change of the *IH* electric cooker, T_1 and T_2 are the minimum and maximum of the temperature control interval of the *IH* electric cooker.

25 2. The non-intrusive induction heating (IH) electric cooker operating identification method based on hybrid criteria according to Claim 1, characterized in that the range of sampling frequency f in Step 1) is $0.5kHz \sim 2kHz$.

3. The non-intrusive induction heating (IH) electric cooker operating identification method based on hybrid criteria according to Claim 1, characterized in that the average active power sequence $P(t)$ and the average reactive power sequence $Q(t)$ in Step 1) are calculated by the following formula:

$$P(t) = |U|_0 * |I|_0 * \cos(\Delta\varphi)$$

$$Q(t) = |U|_0 * |I|_0 * \sin(\Delta\varphi)$$

5 where

$$|U|_0 = \frac{2\sqrt{U_x^2 + U_y^2}}{N}$$

$$|I|_0 = \frac{2\sqrt{I_x^2 + I_y^2}}{N}$$

$$\Delta\varphi = \arctan\left(\frac{U_y}{U_x}\right) - \arctan\left(\frac{I_y}{I_x}\right)$$

N is the number of points of FFT analysis,

$$U_N = FFT(u(t))$$

$$I_N = FFT(i(t))$$

10 wherein, $t=t_0+1, t_0+2, \dots, t_0+N$, t_0 is the current and voltage sampling sequence number, N is the number of points for fast Fourier transformation, t is the time point, FFT is the fast Fourier transformation function, N complex points are obtained after fast Fourier transformation of N points, then the frequency represented by the n th point is $fn=f*n/N$, wherein, $n=0, 1, 2, \dots, N-1$, the 0th point represents the DC component, the fundamental wave is calculated as per $n_0=N*f_0/f$, for the complex sequences U_N and I_N , the complex number corresponding to the point n_0 of the fundamental wave is recorded as follows:

$$U_N(n_0) = U_x + jU_y$$

$$I_N(n_0) = I_x + jI_y$$

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wherein, j is a complex unit.

4. The non-intrusive induction heating (IH) electric cooker operating identification method based on hybrid criteria according to Claim 3, $f_0=50Hz$.

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5. The non-intrusive induction heating (IH) electric cooker operating identification method based on hybrid criteria according to Claim 3, characterized in that N is the integer power of 2.

6. The non-intrusive induction heating (IH) electric cooker operating identification method based on hybrid criteria according to Claim 1, characterized in that the active power change ΔP_{on} and the inactive power change ΔQ_{on} and the active power change ΔP_{off} and the inactive power change ΔQ_{off} during switching-off in Step 2) are obtained by the following formula:

$$\Delta P_{on}=P(t_s+\Delta t_s)-P(t_s)$$

$$\Delta Q_{on}=Q(t_s+\Delta t_s)-Q(t_s)$$

$$\Delta P_{off}=P(t_e)-P(t_e-\Delta t_e)$$

$$\Delta Q_{off}=Q(t_e)-Q(t_e-\Delta t_e)$$

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wherein, t_s and t_e are for the rise step time and fall step time respectively, representing the on time and off time of a load, Δt_s and Δt_e represent the minimum time interval of the active sequence point and the minimum time interval of the reactive sequence point respectively.

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7. The non-intrusive induction heating (IH) electric cooker operating identification method based on hybrid criteria according to Claim 1, characterized in that the operation time of the IH electric cooker in Step 3) comprises the operation time interval Δt_{on} , the stopping time interval Δt_{off} and the temperature control time interval Δt_{ctr} , wherein, $\Delta t_{ctr} > 2 * \Delta t_{off}$,

the temperature control time interval Δt_{ctr} is screened according to the above formula.

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