ABSTRACT
Nowadays, the residential load increasing rapidly and have a very huge potential for demand response. The Non-Intrusive Load Monitoring (NILM) used in this paper can detect devices from the total current and voltage of user’s incoming line instead of entering the households. In this study, a new application of NILM in demand response was researched, which was used to measure the demand response potential of home air conditioners. NILM obtains the comfort limits of regional air conditioners based on the overall usage of air conditioners in the same area. Moreover, the calculation method of residential air conditioning demand response potential is proposed.

INTRODUCTION
With the improvement of the living standard of urban residents in China, the proportion of residential electricity consumption in the whole society is getting higher. In 2016, the proportion of the newly increased residential electricity consumption in China was nearly 40% [1-2]. In addition, due to the climate warming, the proportion of residential air conditioning load also increased significantly. In hot regions such as Nanjing and Guangzhou, air-conditioning load in summer accounts for about 30% of the maximum load, which further widen the peak and valley difference of the power grid in summer [3-4]. The short-term power shortage caused by air-conditioning power consumption even has an impact on the safe and stable operation of the power grid. Demand side management of the power grid adjusts users’ electricity behaviour by means of management, and urges users to stagger the use of air-conditioners at peak hours of the power grid by means of electricity price and incentive, which can effectively restrain the peak of the power grid and delay the demand of new power plants [5-6].

The power grid company must know the operation state of each user’s air conditioners, so as to interact with users in real time through mobile apps and other media, and encourages some users to stagger time with each other to use air conditioning. Presently, there are two kinds of technical measures to monitor the operation state of users' air conditioners: the first plan needs to enter the user's house to install smart sockets, and each air conditioner needs to be monitored separately. The disadvantage is that it needs to enter the interior of the user's construction, which is difficult to be popularized on a large scale. The second plan is called non-invasive load monitoring scheme, which does not need to invade the interior of the user's construction, but only needs to collect the user's electricity meter data, and then identify the user's air conditioning operation sequence through a decomposition algorithm [7-9]. The important technical advantage of the non-invasive scheme lies in the use of advanced algorithms to replace the original way of using sensor networks. When installing the non-invasive scheme, the user has no perception at all, so it is very easy to popularize it on a large scale. Currently, the research on non-invasive load identification is still in the theoretical and laboratory stages [9-10]. Therefore, on the basis of NILM, this paper analyses the user's air conditioning usage habits and proposes a new application mode of NILM in demand response. This paper is organised as follows: Section 1 and Section 2 describes the process of load decomposition and the identification method of air conditioners. Section 3 and Section 4 proposes the comfort limits of regional air conditioners and the calculation method of demand response potential of residential air conditioners. Finally, conclusions are presented.

LOAD DECOMPOSITION
Nowadays, the residential load is increasing rapidly and have a very huge potential for demand response. The classical method to analyse this potential is based on abstract model theory, in which residential load is not actually participated in demand response. Accordingly, a method of data collection has been proposed to solve this problem. The traditional residential electricity data
collection method is Intrusive Load Monitoring (ILM). It has to enter the user's home to get the power consumption of each device which costs a lot and is not easy to popularize. The Non-Intrusive Load Monitoring (NILM) used in this paper can detect devices from aggregated data measured from user’s incoming line without entering the households, this is an easy way to generalize and provide data support, which enables families to participate more effectively in demand response management. This paper uses the matching algorithm based on event changes (Figure 1), which is verified by more than 10 households with a comparison system including air conditioners and water heaters. The accuracy of devices’ power consumption is above 85%.

Through the decomposition of residential users' electricity load, the composition of users' electricity consumption can be effectively understood. In this paper, user load is divided into fixed load and adjustable load, so as to effectively analyse the load that can participate in demand side management.

1) Fixed load. It is the load of equipment that will have an impact on users' life because of the adjustment of power consumption time or interruption of power consumption, such as lighting, refrigerators, computers and other appliances. This type of equipment is not suitable to participate in the demand response, so it is less affected by the price of electricity.

2) Adjustable load. It is the load of equipment that can be adjusted or interrupted during working hours, such as air conditioner, water heater and other equipment. The demand response potential of residents can be effectively evaluated through the adjustable potential assessment of this kind of load.

**IDENTIFICATION OF AIR CONDITIONERS**

Due to the summer climate warming, the proportion of residential air-conditioning load also increased significantly. In hot regions such as Jiangsu and Shenzhen, air-conditioning load in summer accounts for about 30% of the maximum load, which further widens the peak and valley difference of the power grid in summer. The short-term power shortage caused by air-conditioning power consumption even has an impact on the safe and stable operation of the power grid. So, this paper mainly studies the demand response potential of residential air-conditioning load.

Figure 2 shows the texture when air conditioners turn on and off. Event detect can be done according to active power. Reactive power, 2nd harmonic and 3rd harmonic are chosen as device load signatures for load decomposition.

**Non-invasive acquisition of voltage and current**

The total voltage and current are collected at the user's total incoming line, and the sampling frequency is 800Hz to form the discrete series of sampling voltage and current.

**Extraction of quaternary feature quantities**

Based on the collected voltage and current, the increment of steady active power is calculated for event detect. And reactive power, 2nd harmonic and 3rd harmonic are calculated as device load signatures for air conditioners.

**Judgment of the start of air conditioners**

The change of active power can be used to determine whether the electrical appliances are on or not. Reactive power, 2nd harmonic and 3rd harmonic are chosen to determine whether it is the air conditioner.

**Judgment of the end of air conditioners**

According to the change of active power, it can judge whether there is a shutdown of electrical appliance and get the final operating period of air conditioners by matching with the opening condition.

**Data reduction of air conditioners**

Divide each day into 96 time periods (every 15 minutes), calculate the running time and power consumption of air conditioners in each time period, and get the average power of this period.

**COMFORT LIMIT OF AREA AIR CONDITIONERS**

In order to understand the adjustable potential of demand response of a single resident, it is necessary to understand the air-conditioning use of residents in the same region. Based on the facts above, a building with 135 households has been chose to install the terminals to get the information of devices in each household, and here comes the following conclusions: Air conditioners are used in 105 households and water heaters are used in 41 households, and the power consumption of air conditioners accounts for a significant proportion of the total power consumption, and the water heaters always run in the morning and evening (Figure 3).
certain households have the shift load potential and the power of their air conditioners can be adjust to $P_{c-limit}$. Also, the comfort limit number of running air conditioners can be obtained as follows:

$$n_{c-limit} = \frac{\sum n_i}{n}$$

Where $n_{c-limit}$ is the value of the average number of air conditioners rounded upwards to the nearest integer. When the user's air-conditioner operating number is greater than $n_{c-limit}$, it can be assumed that the certain households have the shift load potential and the number of their air conditioners can be adjust to $n_{c-limit}$.

**RESIDENTIAL AIR CONDITIONING DEMAND RESPONSE POTENTIAL**

The calculation method of demand response potential of residential air conditioners is as follows:

First, according to the non-invasive load identification terminal, air conditioning usage of households is collected. Second, the air conditioning usage of households in the whole area is sorted out according to 96 periods. The comfort limit of regional air conditioners in each time period is calculated.

Then, according to the comfort limit of regional air conditioners in each period, restrict the air-conditioning usage of each user in the area. The number of each households’ running air conditioners in each period shall not be greater than the comfort limit number of air-conditioning. Also, the average power of each households’ running air conditioners in each period shall not be greater than the comfort limit power of air-conditioning.

Finally, calculate the air-conditioning power consumption in each time period of each household in same region after the constraints:

$$W_i = n_i P_{i} T_a$$

Where $W_i$ is the air-conditioning power consumption of household $i$ after the constraints; $n_i$ is the number of household $i$’s running air conditioners after the constraints; $P_{i}$ is the average power of household $i$’s running air conditioners after the constraints; $T_a$ is the duration of household $i$’s running air conditioners.

Take the building with 135 households mentioned in chapter 3 as an example to illustrate the demand response potential of residential air conditioners.

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**Figure 3. Households Power Consumption Stack Figure**

Taking the air conditioners as an example to illustrate residents’ demand response ability, Figure 4 shows the operation of each air conditioner and the distribution of total air conditioners have the same trend with the whole power consumption.

**Figure 4. Use Distribution Map of Air Conditioners**

From 19pm to 20pm, there are 60 households who keep their air conditioners running, 8 of whom keep more than 2 air conditioners running at the same time. Obviously, a conclusion can be made that in this period, each household can just keep one air conditioner running to maintain the temperature of the room, so that 8 households have the shift load potential. Using the same sample from 19pm to 20pm, the average power consumption of the air conditioners is 0.8kwh with 18 households’ power consumption 30% higher than the average. From a general perspective, without considering factors such as brand, energy efficiency, etc., it can be shown that those 18 households’ setting temperature of the air conditioners are lower than the average, so, the certain households have the shift load potential too.

According to the overall usage of air conditioners of residents in the same area, the comfort limit of air conditioners can be obtained. The comfort limit power of air conditioners can be obtained as follows:

$$P_{c-limit} = \frac{1}{n} \sum P_i$$

Where the $n_i$ represents the number of air conditioners in a single user’s home, $P_i$ represents the total power of air-conditioning used in a single user’s home, $n$ is the number of households in the region. The comfort limit power $P_{c-limit}$ is used to adjust the air conditioners with high operating power. When the user’s air-conditioner operating power is greater than $P_{c-limit}$, it can be assumed that the...
Figure 5. Comparison of air-conditioning power consumption

Figure 5 shows the operation of each air conditioner and the distribution of total air conditioners have the same trend with the whole power consumption. After the demand response, the air-conditioning power consumption is 70.2% of the power consumption before the response.

Figure 6. Demand Respond Ability Comparison

Figure 6 shows the comparison of the demand respond ability between a factory and a 1000-households community according to the statistics above. The effect of air conditioners’ load shifting of residents without affecting the households comfort during peak time is similar to a small factory.

CONCLUSION

Non-invasive load monitoring technology is a new advanced measurement technology of smart grid. This paper presents a new application of NILM in demand response. The comfort limit of area air conditioners is obtained by NILM, accordingly, a control and calculation method of demand response potential of residential air conditioners is proposed. This method is applied in a building with 135 households and the conclusion shows that the air-conditioning power consumption after the demand response is 70.2% of the power consumption before the response.

In summary, the application of NILM can provide data support for residents’ demand response and the method in this paper is worth a further study.

REFERENCES