Analysis of Air-conditioning Load Data Based on Wavelet Transform

Min Li\textsuperscript{1}, Yan-chi ZHANG\textsuperscript{1} and Da XIE\textsuperscript{2,*}

\textsuperscript{1}Shanghai Dianji University, 690 Jiangchuan RD. Minhang District, Shanghai, China

\textsuperscript{2}Shanghai Jiaotong University, 800 Dongchuan RD. Minhang District, Shanghai, China

*Corresponding author

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Abstract. A series of map and coefficient matrix were obtained by using the Morlet wavelet transform for the data of air conditioning in an office building, and the characteristics of the graph were analyzed in this paper. Then the coefficient matrix was used to draw 3D image rendering and contour image drawing, and explore the implications of these data from different perspectives.

Introduction

The development of science and technology has made the air conditioner better and better, it has laid the foundation for turning air conditioning equipment into a very popular household appliance. The development of economy and the improvement of people’s living standard make air conditioners become necessary household appliances for every household\textsuperscript{[1]}. On the one hand, the increasing of air conditioning load makes the load characteristics of the network worse and the power shortage of the peak electricity during the peak season has brought great negative impact on the safety and economic operation of the power grid. On the other hand, the air conditioning load has become an important demand response resource under the smart grid with its high response speed and high potential\textsuperscript{[2]}. Therefore, it is necessary to analyze the characteristics of air conditioning load so as to implement reasonable scheduling control and improve its load characteristics, and it can also fully tap its demand response potential to make it become the power grid friendly load and improve the operation efficiency of power system.

Air conditioning load has the following characteristics: Seasonal, air conditioning load is greatly influenced by meteorological factors, especially temperature, humidity, solar radiation, etc., and it presents a strong correlation. Similarity, due to the daily external meteorological factors and the rules of human activities, the position change of peak time point of daily air conditioning load curve is very small and the shape of the curve is also very similar. Smoothness, since the short-term internal and external factors have not a large degree of change and the impact on the load is also a gradual process, so the slope of the daily air conditioning load curve is generally uniform and the adjacent points won’t have a larger jump. Periodic volatility, the load of air conditioning system tends to be low in the morning and evening and the maximum load is reached around 1:00 PM, such as summer load. Multi-dimensional, the objective attribute of things is multidimensional, therefore, a variety of measures are used to evaluate the operating conditions of air-conditioning. In addition, the corresponding air conditioning load forecasting has the characteristics of unknown, comprehensive, progressive and so on\textsuperscript{[3]}. Domestic and foreign scholars have done a lot of research. The paper\textsuperscript{[4]} analyzes the air conditioning load characteristics of the air conditioning in the capital airport terminal 2 in the spring and summer, and find out the critical state and rule of air conditioning in different situations. The paper\textsuperscript{[5]} used box figure out method to deal with the data of 15 air-conditioned cooling load time distribution curves and find out the time distribution rule. It is concluded that frequency distributions of the benchmark is fiat with the approximate conclusion of the normal distribution. In\textsuperscript{[6]}, Motegi N and other scholars introduced the control strategy and technology of power load in commercial buildings from the demand response level and focus on the demand response control strategy of HVAC air conditioning, and also puts forward ten control strategies such as limiting fan speed and closing a certain number of fans. This paper also studies
whether the implementation of these strategies will rebound after implementation, and proposes
three control methods to minimize the post-adjustment load. In the paper [7], scholars such as PieRe
MA introduced a demand response project in 2003 and some demand response strategies are
implemented for 5 users. The energy saving potential of these users is studied in high temperature
weather, and also found that these users had a load rebound when they finished DR project.

At present, the research literature on air conditioning load mainly focuses on the analysis of air
conditioning load characteristics. Few people are specifically analyzing the power data generated by
the air-conditioning operation. In this paper, an office building air-conditioning power consumption
data as an example to analyze, and the information hidden behind the data of power consumption is
mined by the Morlet wavelet transform of the electricity consumption data.

The Basic Principle of Wavelet Transform

The concept of wavelet transform was proposed by the French geophysicist J. Morlet in the analysis
of physical data exploration in 1984. The mathematical basis of wavelet transform is the Fourier
transform of the 19th century and theoretical physicist A. Grossman established the theory system
of wavelet transform using translation and scale invariance. In 1985, Y. Meryer, a French
mathematician, first constructed a smooth wavelet with a certain attenuation. In 1988, the Belgian
mathematician I. Daubechies demonstrated the existence of the compact support orthogonal
standard wavelets and Make discrete wavelet analysis possible. In 1989, S. Mallat proposed the
concept of multiresolution analysis and the methods of constructing wavelets before this are unified,
A fast algorithm for binary wavelet transform is presented and it makes the wavelet transform more
practical[8].

The meaning of the wavelet transform: The function of a basic wavelet $\psi(t)$ is displacement $\tau$,
and then the inner product at different scales of a with respect to the analysis signal $x(t)$ are done.

$$\text{WT}_a (a, \tau) = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} x(t) \psi^* \left( \frac{t-\tau}{a} \right) dt$$

(1)

The equivalent frequency domain is expressed as:

$$\text{WT}_a (a, \tau) = \frac{1}{2\pi} \int_{-\infty}^{\infty} X(\omega) \psi^* (a\omega) e^{i\omega \tau} d\omega$$

(2)

In equation (2), $X(\omega), \psi(\omega)$ is the Fourier transform of $x(t), \psi(t)$ respectively.

The definition and properties of continuous wavelet transform: If $\psi(t)$ is a square integrable
function, that is to say $\psi(t) \in L^2 (R)$, if its Fourier transform $\psi(\omega)$ satisfies the condition:

$$C_\psi = \int_\omega |\psi(\omega)|^2 d\omega < \infty$$

(3)

$\psi(t)$ is called a basic wavelet or wavelet mother function, formula (3) is the allowable condition
of wavelet function. Function $f(t)$ is unfolding under the wavelet base in any $L^2 (R)$ space. This
unfolding process is called continue wavelet transform of function $f(t)$, referred to as CWT. The
expression is:

$$\text{WT}_a (a, \tau) = [f(t), \psi_{a,x}(t)] = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} f(t) \psi^* \left( \frac{t-\tau}{a} \right) dt$$

(4)

This paper uses Morlet wavelet transform for data analysis. The Morlet wavelet is defined as:

$$\psi(x) = \pi^{-1/4} \cos(kx)e^{-x^2/2}$$

(5)
Where, $k$ is the wave number.

**Example and Simulation**

**Analysis of Examples**

This paper selects the air conditioning power consumption in July and August from a large electricity consumer to analyze. As is shown in Fig.1, it is the July original time sequence diagram. As is shown in Fig.2, it is the August original time sequence diagram. The horizontal represents the time, and the ordinate represents the value of user's lightning electricity consumption.

![Figure 1. Original time sequence diagram of July.](image1)

![Figure 2. Original time sequence diagram of August.](image2)

The graph is based on the real-time transmission of air-conditioning power consumption data in the smart meters installed in the office building. Smart meters record a set of data per hour, 744 sets of data are formed each month and draw these data into the original time sequence diagram. We can easily find the existence of certain cyclical from the overall situation. Workday electricity consumption is large, and the trend is stable and the electricity consumption on the weekend is very small. If we have a close-up view of the chart, we can find that the amount of electricity used during the day is significantly higher than that used in the evening. By using the statistics of large amount of electricity, we can see the electricity rule of an office building intuitively. Of course this is just the most intuitive information from the data. This paper hopes to make wavelet transform of these electricity data and discover some different information from another perspective.

**Example Simulation**

The power consumption data of air conditioner in the main building of office building are imported into the software in July and August into. The Morlet wavelet transform of different scales is carried out, and the following two graphs are obtained:
Fig. 3 shows the frequency characteristics of the original data of air conditioning power consumption in July with the Morlet wavelet transform respectively at 1, 2, 5, 10, 20, and 50, 100, 200, 500, 1000, 10 scales. As can be seen from the figure, the waveform of the small scale (1, 2, 5, 10, 20) shows periodic change, while the waveform of the large scale (50, 100, 200, 500, 1000) has no obvious periodicity. In the position of 200, 380, 520, the waveform only has frequency response at large scale, and there is no frequency response at small scale. As the scale increases, the frequency fluctuation range increases gradually. Fig. 4 shows the frequency characteristics of the original data of air conditioning power consumption in August. Compared to figure 3, it can be found that they have similar variation patterns and it's just a different frequency range.

At the same time, the software will automatically form a set of coefficient matrix corresponding to the wavelet transform. For a more intuitive observation of the result of wavelet transform, we plot the coefficient matrix in three dimensions, as shown in figure 5 and figure 6.

For contour plotting, as shown in figure 7 and figure 8. Combined with three-dimensional and contour maps, we can find that the frequency of July is mostly in the range of -270 to 250, and the frequency of August is mostly between -21.25 and 261.3, both of the images in the two months show periodic changes in the vicinity of the Y-axis at 5, with the Y-axis being the largest in the vicinity of 10.
Conclusion

In this paper, a series of graphs are obtained for the Morlet wavelet transform of the air conditioning power data of an office building, and the coefficient matrix is presented in three dimensions. The following conclusions are obtained through the analysis of the image.

(1) The waveform changes periodically in small scale and as the scale increases, the frequency fluctuation range increases gradually.
(2) The point with no frequency response at a small scale and frequency response at large scales. The range of frequency variation is concentrated in a certain range.
(3) The coefficients matrix images of the two months have periodic transformations in the Y-axis around 5 and the highest in the vicinity of 10.

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References