Calculating the winter base load and AC load in Chongqing considering the correlation of temperature and power system load

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Abstract. The widely use of air conditioning (AC) equipment have brought a large amount of AC load to the power grid, which has an increasingly impact on the safe and economic operation of the power system. In order to correctly estimate the scale of AC load, this paper proposes a new winter AC load calculation method considering the correlation of temperature and load. Firstly, abnormal temperature days (ATD) are removed from the set of representative days (RD) by calculating the correlation coefficient of temperature and load in RD screening process. Secondly, taking into account the daily growth of the base load, the regression analysis is used to fit the base load curve for each day in winter. Then the spring festival (SF) coefficient is proposed to modify the system base load in SF because power system load decreases dramatically during SF. Finally, the winter AC load is equal to the difference between winter power system load and winter base load. The winter AC load in Chongqing 2018 is calculated using the proposed method and the result shows the effectiveness of this method.

1. Introduction
In recent years, air conditioning (AC) load has become a significant part in power system load, especially in the south part of China, where the AC equipment is the main device providing heat in winter. With the increase of AC load, the power system load factor decreases and the peak-valley difference increases, making it harder to stabilize the system voltage. At the same time, it poses a severe challenge to the power grid peak shaving and frequency regulation [1]-[2]. In the voltage collapse accident in Tokyo 1987, the AC load increased sharply at noon and the system suffered from the lack of re-active load. Then the system voltage lost stability and finally the grid voltage collapsed [3]. System operators can’t get statistic data of all the AC equipment directly, limited to the present technical and management ability. Thus, the AC load can only be evaluated based on the power system load data. Peak-load comparison method (PLCM) and basic-load comparing method (BLCM) are the widely-adopted methods by system operators to calculate AC load. In PLCM, the daily peak AC load is equal to the difference between daily peak load in winter and daily peak load of the day without AC load [4]-[5]. In BLCM, the winter base load is obtained by calculating the average value...
of all the representative days (RD) in spring and autumn. Then the AC load is equal to the difference between power system load and base load. However, there are two problems in these two conventional methods. Firstly, power system load has a natural growth trend, which is neglected in both PLCM and BLCM. Secondly, a fixed period is used as RD set in BLCM, during which ab-normal temperature day (ATD) may occur. It means that the power load of the selected RD set may be affected by temperature and the AC load can be miscalculated.

In this paper, a new method to evaluate the AC load is proposed considering the correlation between temperature and power system load. At first, ATD is identified and removed by calculating the correlation coefficient of temperature and load of RD set. Then a set of new RD is get, whose power system load is hardly influence by temperature. To account for the natural growth of base load, the regression analysis is used to fit the base load curves for each day in winter. Power system load decreases dramatically during spring festival (SF). Thus, the SF coefficient is proposed to modify the system base load in SF. Finally, the winter AC load is the difference between winter power system load and winter base load.

The rest of the paper is organized as follows. A RD choosing method is proposed considering the correlation of temperature and power system load in section 2. A base load calculation method is proposed in section 3 based on regression analysis. The influence of SF to power system load is discussed and SF coefficient calculation method is proposed in section 4. We show the calculation process of the paper in section 5. Section 6 is the case study and section 7 is the conclusion.

2. A new RD choosing method considering the correlation of temperature and power system load

AC device is mainly used for heating during winter and cooling in summer. The ab-normal temperature has direct relationship with AC load. The temperature is suitable for people in spring and autumn, generally no AC load appears. Thus, spring days and autumn days are suitable as the RD for base load calculating [6]-[7]. However, the temperature in spring and autumn may be abnormal, like late spring coldness phenomenon. In other words, not all the days in spring and autumn are suitable as the RD. No AC load is allowed to appear in an ideal RD set and the power system load of which shows no relationship with temperature. When abnormal weather occurs in spring and autumn, the daily power system load will increase, which results in a certain correlation between load and temperature. In this paper, a RD choosing method is proposed based on the calculation of correlation coefficient of temperature and power system load. In order to calculate the AC load of this winter, we need to select RD set from this fall and next spring.

If we choose a RD subset from autumn, the choosing process is as follows:

1) Choose typical months and select all days in these months to form the initial RD set \( \Omega_{\text{aut}} \).
2) The daily electrical energy consumption is obtained from the hourly load of RD in the RD set.

\[
E_{\text{aut},j} = \sum_{i=1}^{24} P_{\text{aut},j,i} \Delta t
\]  

where, \( E_{\text{aut},j} \) is the \( j_{th} \) daily electrical energy consumption in the RD set. \( P_{\text{aut},j,i} \) is the \( i_{th} \) hourly load in the \( j_{th} \) day. \( \Delta t \) is duration. To be simple, the subscript ‘aut’ is omitted in the follow part of the paper.

3) Calculate the correlation coefficient \( \rho \) between daily base load and daily average temperature. The formulation is shown in (2). The smaller \( \rho \) indicates the weaker correlation. To evaluate the strength of correlation, \( \rho=0.4 \) is set as the threshold. If \( \rho<0.4 \), the load and temperature is in weak correlation [8]. Then the present set is the ideal RD set and the process is put into an end. If not, go step 4.
where, \( D_N \) is the number of elements in present set. \( \bar{E} \) is the average daily electrical energy consumption and the formulation is shown in (3). \( T_{\text{mean},j} \) is the average temperature of \( j \)th day in RD set. \( T_{\text{mean}} \) is the average temperature of all day in RD set and the formulation is shown in (4). \(|\cdot|\) is the symbol of absolute value.

3) Find the day with the biggest \( \Delta T_{\text{mean},j} \), where \( \Delta T_{\text{mean},j} \) is the difference between daily average temperature and average temperature of the present RD set. Then remove that day from the set to obtain the new set of RD. Go back to step 2.

The RD subset of next spring can be obtained in the same way. The RD subset of this autumn and next spring make up the complete RD set for winter AC load calculating.

3. Winter base load calculation based on regression analysis

In winter, power system load is not only influenced by temperature, but also by the economy growth and other factors. Power system load has the trend of increasing steadily. To evaluate the winter AC load precisely considering the increasing trend, regression analysis is used in this section.

Regression analysis is a classical data analysis method in statistics. The mathematical relationship between dependent and independent variables is determined by establishing regression equation in regression analysis. In this paper, the independent variable is the date of each day in winter, and the dependent variable is the base load of \( h \)th hour in each day of winter. Due to the different load characteristic of weekdays and weekends, weekdays subset of RD is used to calculate the base load of winter weekdays, weekends subset of RD is used to calculate the base load of winter weekends. A quantitative fitting method is deployed to get the hourly load in winter weekdays and weekends considering the growth trend. Taking the calculation of base load value at 1 o’clock in winter weekdays as an example, the choosing process is as follows:

1) Firstly, four models are used to fit the load.
   a) Linear model
      \[ P_{b,w,1} = a_1 t + b_1 \] (5)
   b) Parabolic model
      \[ P_{b,w,1} = a_2 t^2 + b_2 t + c_2 \] (6)
   c) Exponential model
      \[ P_{b,w,1} = a_3 e^{b_3 t} \] (7)
   d) Logarithmic model
      \[ P_{b,w,1} = a_4 + b_4 \ln t \] (8)

   where, \( a_1, a_2, a_3, a_4, b_1, b_2, b_3, b_4, c_2 \) are unknown parameters to be estimated. In this paper, the least square method is used to solve the parameters.

2) Calculate the determination coefficient \( R^2 \) of each model, and the indicator is used to test the fitting effect of different regression models. Larger determination coefficient shows a better
effectiveness of regression model[9]. The model with the largest coefficient is selected as the optimal fit equation.

3) Calculate the base load at 1 o’clock in winter weekdays using the selected model. The base load value from 2 o’clock to 24 o’clock in winter weekdays can be obtained easily in the same way. Similarly, the base load in weekends is calculated by using the weekends data. The winter base load curve is then obtained by splicing all the hourly load value.

4. Modifying the winter base load considering the SF coefficient

The base load curve calculated in section 3 does not take into account the impact of Spring Festival (SF) on social electrical energy consumption. The SF generally in January or February and the power system load during the SF will go through a significant decline due to the shutdown of the factory and public holidays[10]. The load characteristic during SF is different from that of ordinary days. A modification should be made towards winter base load considering the SF factor.

In order to take into account the influence of the SF, five days before New Year’s Eve to fifteen days after New Year’s Eve are set as the SF impact period. Two weeks before the SF impact period is set as the reference period for calculating the SF coefficient. SF coefficient calculation formula is in (9):

$$\lambda_n = \begin{cases} \frac{E_n}{E_{BF,w}}, & n \in \Omega_{SF,w} \\ \frac{E_n}{E_{BF,o}}, & n \in \Omega_{SF,o} \\ 1, & n \in \Omega_{SF} \end{cases}$$  

where $\lambda_n$ is the SF coefficient for $n_{th}$ day. $\Omega_{SF}$ is the set of SF impact period. $\Omega_{BF,w}$ and $\Omega_{BF,o}$ are the subset of weekdays and weekends of $\Omega_{SF}$. $E_n$ is the daily electrical energy consumption for $n_{th}$ day, which is calculated by formula (1). $E_{BF,w}$ is the average electrical energy consumption in weekdays in SF reference period, while $E_{BF,o}$ is the average electrical energy consumption in weekends in SF reference period.

The base load curve considering SF influence is calculated in (10):

$$P_{B,n,h} = \lambda_n P_{B,n,h}$$  

where $P_{B,n,h}$ is the $h_{th}$ hourly load in $n_{th}$ day before modification and $P_{B,n,h}$ represent the modified hourly load.

5. Winter AC load calculation process

Firstly, select all the days in typical spring month and autumn month to form the initial RD set. Execute the screening process to initial RD by considering the correlation between temperature and power system load. The subset of weekdays and weekends are obtained accordingly. Secondly, regression analysis is deployed to get the winter base load and SF coefficient is calculated to modify the winter base load. Finally, the winter AC load is the difference between winter power system load and winter base load.

$$P_{AC,n,h} = P_{L,n,h} - P_{B,n,h}$$  

In this formula, $P_{AC,n,h}$ is the $h_{th}$ hourly AC load in $n_{th}$ day. $P_{L,n,h}$ is the $h_{th}$ hourly power system load in $n_{th}$ day.

The AC load calculation process is shown in Fig. 1.
6. Case study

6.1. Case Introduction

In this section, the winter AC load in Chongqing 2018 is calculated based on the hourly load data and daily average temperature data from September 1\textsuperscript{st}, 2018 to July 30\textsuperscript{th}, 2019. Chongqing has a typical continental monsoon climate. The heating demand in Chongqing winter is high and air-conditioning equipment is the main equipment for providing heat. In this paper, September 1\textsuperscript{st}, 2018 to October 31\textsuperscript{st}, 2018 is set as the autumn of 2018. November 1\textsuperscript{st}, 2018 to February 28\textsuperscript{th}, 2019 is the winter of 2018. March 1\textsuperscript{st}, 2019 to April 30\textsuperscript{th}, 2019 is the spring of 2019. The hourly load curve of Chongqing winter 2018 is shown in Fig. 2. We can see that the daily load curves in winter have the similar shape. There are two peaks in the curve occurring in the morning and night in every day. In addition, it is obvious that the load level decreases during SF.

![Flowchart](image)

**Figure 1.** AC load calculation process

![Load curve](image)

**Figure 2.** Winter daily load curve of Chongqing 2018
6.2. *Analysis to the winter AC load in Chongqing 2018*

Base on the RD choosing method in section 2, all the ATD in fall 2018 and spring 2019 is removed from the original RD set. Then we get the spring RD set and autumn RD set. Take autumn 2018 as an example, Fig.3 shows the daily electrical energy consumption and average temperature in autumn 2018 in Chongqing. It shows that the average temperature went through an increase in both September 1st, 2018 and September 19th, 2018. At the same time, the AC load increased too, which caused two load peaks in the two periods. As a result, the correlation between power system load and temperature in autumn 2018 is relatively high.

Table 1 shows the average temperature of ATD and the correlation coefficient $\rho$ in the screening process of autumn 2018. In the process, abnormal temperature data is detected and removed from initial the RD set. It can be seen that the two high-temperature weather processes in September are included in removed ATD set. As the screening process progresses, and the correlation between power system load and temperature decreases.

![Daily electrical energy consumption and average temperature in autumn Chongqing 2018](image)

**Table 1.** The RD set screening process in autumn 2018

| Screening Time | Removed ATD | Average Temperature of ATD | Correlation Coefficient $\rho$ after Screening |
|----------------|-------------|-----------------------------|-----------------------------------------------|
| 1              | 2018/09/02  | 34                          | 0.579                                         |
| 2              | 2018/09/01  | 33.9                        | 0.552                                         |
| 3              | 2018/09/04  | 33.7                        | 0.515                                         |
| 4              | 2018/09/05  | 33.1                        | 0.496                                         |
| 5              | 2018/09/03  | 32.7                        | 0.506                                         |
| 6              | 2018/09/19  | 27.5                        | 0.494                                         |
| 7              | 2018/09/23  | 25.3                        | 0.472                                         |
| 8              | 2018/09/20  | 24.7                        | 0.471                                         |
| 9              | 2018/09/21  | 23.4                        | 0.431                                         |
| 10             | 2018/09/06  | 23.2                        | 0.449                                         |
| 11             | 2018/09/18  | 23.2                        | 0.436                                         |
| 12             | 2018/09/22  | 22.8                        | 0.407                                         |
| 13             | 2018/09/09  | 22.6                        | 0.374                                         |

Regression analysis is used to fit the hourly base load in winter based on the daily load curve of autumn RD and spring RD. January 30th, 2019 to February 19th is set as the SF influence period and January 16th, 2019 to January 29th is set as SF reference period. Based on the daily load data, the SF coefficient during SF is calculated. Table 2 shows SF coefficient of four days around SF. It can be seen that the power system load in Chongqing decreased before SF and increased after SF but the impact of SF towards power system load didn’t completely disappear after fifteen days of the Chinese New Year’s Eve. The original base load is multiplied by SF coefficient and the adjusted base load curve in...
Chongqing 2018 is obtained accordingly. The winter AC load in Chongqing 2018 is equal to the difference between power system load and base load, which is shown in Fig. 4.

| Date       | SF Coefficient |
|------------|----------------|
| 2019/02/01 | 0.740          |
| 2019/02/04 | 0.537          |
| 2019/02/05 | 0.487          |
| 2019/02/19 | 0.884          |

**Table 2. SF coefficient of four days in winter of 2018**

6.3. *Analysis of calculation results compared to BLCM*

To verify the effectiveness of the proposed AC load calculation method, BLCM is used to calculate the winter AC load in Chongqing 2018 and Fig.5 shows the winter AC peak load curves in Chongqing 2018 calculated by the proposed method and BLCM. It can be seen that the two curves in Fig.5 have the same trend. However, the AC peak load in early winter calculated by BLCM is lower than that by the method proposed in this paper. It is because that BLCM using the same base load curve for the entire winter. The base load curve is obtained by calculating the average value of RD in autumn 2018 and spring 2019, which leads to the calculated based load in early winter is higher and the AC load is lower.

We also calculated correlation coefficient between winter peak AC load and different types of temperature, including daily peak temperature, daily valley temperature and daily average temperature. The results are shown in Table 3. We can see that the peak AC load has the strongest relationship with daily average temperature, compared to that with daily peak temperature and daily valley temperature, calculated in both methods. It is also easy to find that AC load calculated by proposed method has stronger correlation with different types of temperature, which illustrates the correctness and effectiveness of the proposed AC load calculation method.

**Figure 4. Winter AC load curve in Chongqing 2018**

**Figure 5. Winter AC peak load in Chongqing 2018 using two methods**
### Table 3. Correlation coefficient of winter peak AC load and different types of temperature in two methods

| Type of Temperature          | Proposed Method | BLCM  |
|-----------------------------|-----------------|-------|
| Daily Peak Temperature      | -0.6772         | -0.5846 |
| Daily Valley Temperature    | -0.6057         | -0.5725 |
| Daily Average Temperature   | -0.6863         | -0.6214 |

7. Conclusions

A new winter AC load calculation method is proposed in this paper. A screening process is deployed to remove the ATD from the initial RD set. After the screening process, a set of RD hardly influenced by temperature is obtained. Regression analysis is carried out to consider the growth trend of base load and SF coefficient is calculated to consider the impact of SF towards power system load. Finally, the proposed method is used in calculating the winter AC load in Chongqing 2018. The results are compared to the results using BLCM. It is concluded that the load calculated by the proposed method has higher correlation with temperature, which illustrate the correctness and effectiveness of the proposed method.

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