Electrical Power and Energy Systems 73 (2015) 913–918

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

# Modification method to deal with the accumulation effects for summer daily electric load forecasting

Yang Li [a], Yu-Qing Bao [a,*], Bin Yang [b], Chu Chen [b], Wenjun Ruan [b]

[a] School of Electrical Engineering, Southeast University, Nanjing, People's Republic of China
[b] State Grid Jiangsu Electric Power Company, Nanjing, People's Republic of China

ARTICLE INFO

*Article history:*
Received 20 May 2014
Received in revised form 14 May 2015
Accepted 16 June 2015
Available online 27 June 2015

*Keywords:*
Load forecasting
Accumulation effect
Genetic-algorithm
Neural network

ABSTRACT

Due to the summer heat, electric load is sometimes influenced by the accumulation effect: the load is not only affected by the present temperature, but also affected by the continuous high-temperature in the last a few days. This paper proposes a method to deal with the accumulation effect. In the proposed method, the temperature variable used in the forecasting model is modified as a function of present and historical temperatures. To enhance the predicting power of the modified temperature, genetic-algorithm (GA) is adopted to get the optimal parameters of the modification function. The testing results show that the modification of the temperature can improve the accuracy of summer load forecasting.



## Introduction

Electric load forecasting is very important for the power system operation and scheduling. So far, a lot of methods, i.e. regression methods [1,2], artificial neutral network (ANN) [3,4], support vector machine (SVM) [5,6] have been developed for short-term load forecasting.

Daily electric load is influenced by many factors such as historical load, weekday index, weather factor, and social factor. To forecast the electric load, the weekday index, predicted weather, and most recently available load are usually selected as the input variables. Among the influencing factors, the temperature is considered as a key factor that affects the daily peak load, especially in summer. Because the air conditioning account for significant part of total electric load, the electric load is very sensitive to the variation of the temperature. Once the temperature rises up, the electric load will increase.

The relationship between the temperature and the electric load has been analyzed in many research works [7–10]. However, very few works focused on the accumulation effects except [11,12]. The accumulation effect occurs in hot summer days. In [12], the accumulation effect is interpreted as the phenomenon of higher peak load caused by the prolonged high temperature. If the high temperature lasts for long, the load will be higher than that without sustained high temperature.

In the east and south China, the maximum temperature in the summer usually exceeds 37 °C. And the accumulation effect is the common problems in these areas. The accumulation effect could add errors to the load forecasting in summer. To solve this problem, [11] and [12] proposed modification methods. By introducing to the forecasting model some new variables that reflect the degree of the accumulation effect, the accuracy of the load forecasting can be improved. However, the determining of the parameters for the modified forecasting model was not well discussed.

This paper makes detailed analysis of the accumulation effect, and proposes a genetic-algorithm (GA) based method to modify the load forecasting model. Compared with previous works, the main novelties and contributions of this paper are as follows:

1. The accumulation effect is analyzed in detail. Not only the short term accumulation effect but also the long term accumulation effect is analyzed.
2. The modification method is proposed: the temperature variable is modified as a function of present and historical temperatures, in order to eliminate the accumulation effect.
3. GA is adopted to get the optimal parameters of the modification function.

To implement the proposed method, the electric load of the Nanjing city is studied. The load data are from State Grid Nanjing Power Supply Company. The following of this paper is organized

* Corresponding author at: School of Electrical Engineering, Southeast University, Sipailou No. 2, Nanjing 210096, People's Republic of China. Tel.: +86 15861813535.
*E-mail address:* 503000747@qq.com (Y.-Q. Bao).

http://dx.doi.org/10.1016/j.ijepes.2015.06.027
0142-0615/

as follows: In Section 'The accumulation effect', the accumulation effect is analyzed. In Section 'Genetic algorithm based modification method', the GA-based modification method is proposed. Testing results are provided in Section 'Daily peak load forecasting'. Finally, the conclusions are summarized in Section 'Conclusion'.

## The accumulation effect

The temperature is one of the driving factors that influence the electric load. Fig. 1 shows the scatter plot of daily peak load $P_d$ versus the temperature $T_d$ in Nanjing around the summer of 2013 (with all the holidays removed). It can be seen that the correlation between the temperature and the load is positive. A regression line can be calculated to estimate the relationship between the load and temperature. By the 2nd order least square fitting, the regression line is obtained (the solid-line in Fig. 1).

The accumulation effect is usually caused by sustained high temperature [11]. When the temperature is above 25–30 °C, the accumulation effect is very obvious. By the length of time scales, the accumulation effect can be separated into long term accumulation effect and short term accumulation effect.

### *Long term accumulation effect*

Long term accumulation effect lasts for a long period of time. The time scale is as long as several weeks, or even months. In Fig. 1, the scatter points of $P_d$ versus $T_d$ in different durations of summer are marked with different symbols. It can be obviously seen that most of the scatter points in the early summer (from May 1 to July 10) lies below the regression curve, whereas most of the scatter points in the late summer (from July 11 to September 30) are above the regression curve, indicating that the daily peak load in the late summer is at a higher level than that in the early summer. As the hot days lasts, the daily peak load becomes higher.

### *Short term accumulation effect*

Short term accumulation effect lasts for a few days. Fig. 2(a) and (b) are two typical examples of short term accumulation effect. It can be seen that the temperature varied very little (less than 0.5 °C) from July 1 to July 4 and from July 23 to July 25. However, the peak load went up day by day (increased more than 9% in 3–4 days).

To further show short term accumulation effect, Fig. 3 shows the scatter plot of $P_d$ versus $T_{d-1}$, $P_d$ versus $T_{d-2}$, and $P_d$ versus $T_{d-3}$, where $T_{d-1}$, $T_{d-2}$, $T_{d-3}$ denote lagged temperature up to 3 days

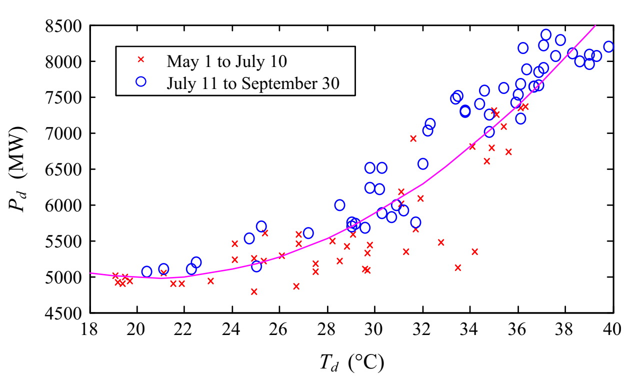


**Fig. 1.** Daily peak load versus maximum temperature in different durations in the summer of 2013.

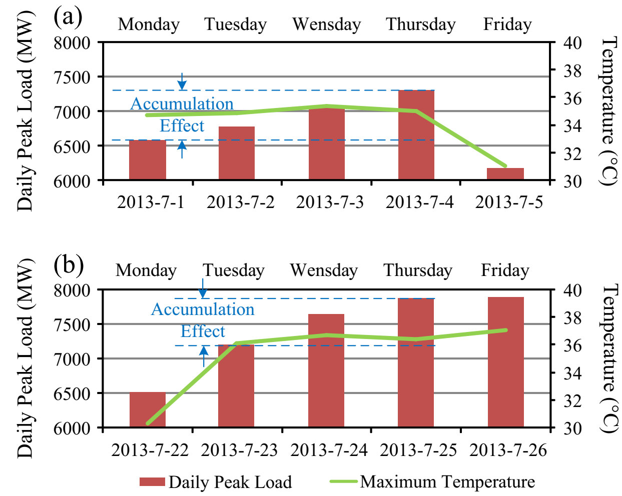


**Fig. 2.** Two examples of short term accumulation effect: daily peak load versus maximum temperature (a) from July 1 to July 5, and (b) from July 22 to July 26.

ago. It can be seen that the general patterns in Fig. 3 are linear. The Pearson product-moment correlation coefficient is used herein to measure the linear relationship between $P_d$ and $T_{d-1}$, $T_{d-2}$, $T_{d-3}$. Given the $n$ samples of two variables $X$ and $Y$ which is denoted by $\{X_1, X_2, \ldots, X_n\}$ and $\{Y_1, Y_2, \ldots, Y_n\}$, the correlation coefficient between $X$ and $Y$ is written as:

$$\mathrm{COR}(X,Y) = \frac{\sum_{i=1}^{n}(X_i - \overline{X})(Y_i - \overline{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \overline{X})^2 \sum_{i=1}^{n}(Y_i - \overline{Y})^2}} \tag{1}$$

The correlation coefficient ranges from −1 to 1. The closer the $\mathrm{COR}(X,Y)$ is to ±1, the stronger linear relationship between $X$ and $Y$. By some calculations based on the temperature and the load data, the correlation coefficients between $P_d$ and $T_{d-1}$, $T_{d-2}$, $T_{d-3}$ can be obtained as following:

$$\mathrm{COR}(P_d, T_{d-1}) = 0.86$$
$$\mathrm{COR}(P_d, T_{d-2}) = 0.78$$
$$\mathrm{COR}(P_d, T_{d-3}) = 0.70$$

The value of $\mathrm{COR}(P_d, T_{d-1})$, $\mathrm{COR}(P_d, T_{d-2})$, $\mathrm{COR}(P_d, T_{d-3})$ are all sufficient large number that reflects strong linear relationship between $P_d$ and $T_{d-1}$, $T_{d-2}$, $T_{d-3}$. It indicates that the historical temperatures in the last a few days also play an important role in determining the daily peak load.

### *Discussion*

In some earlier studies [11,12], only short term accumulation effect is explored. In [11] and [12], the numbers of influencing days are considered to be 4 and 3, respectively. However, the long term accumulation effect, which is introduced above, is not considered in [11] and [12]. The above analysis indicates that not only short term accumulation effect, but also long term accumulation effect has influence on the electric load. Therefore, both the two effects are necessary to be considered in the forecasting.

Actually, the accumulation effect can be considered as the load's inertia to the varying temperature. According to our investigation, the following reasons can account for the accumulation effect:

- Thermal inertia of the ground. The soil temperature varies much more slowly than the air temperature. Sustained high temperature can gradually increase the temperature of the ground as well as the buildings.