Analysis of Electricity Loss and Electricity Consumption Law in Low-Voltage Areas: A Case Study

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Abstract. Electric power is an important resource in energy. With the development of society, the consumption of electric power is more and more. Research on electricity consumption and power loss has become a hot topic. In this paper, we conduct statistical analysis on the power supply, power consumption and line loss rate of 395 power supply stations. Line loss rate is an indicator to describe electricity consumption. We found that the line loss rate decreased over the course of a year. The overall distribution of line loss rate is approximately lognormal distribution. Total daily electricity supply and electricity consumption in the power supply area approximately obey exponential distribution. In terms of electricity consumption, a statistical analysis was made on the daily electricity consumption of 100,000 users in three years, and it was found that the electricity distribution of users was in line with the power law distribution.

1. Introduction

Electricity is an indispensable source of energy in our life. China's electricity generation accounts for more than 25% of the global total [1]. The collection and analysis of electricity data has been difficult in the past because of the large population. With the upgrading of power system and the popularization of intelligent power equipment, State Grid Corporation of China can collect massive real-time data of electricity consumption of users and operation data of power equipment. Therefore, through big data analysis technology, scientific power monitoring has been gradually realized, and it is possible to use this part of data for analysis. The analysis of power consumption behavior is beneficial to improve work efficiency, reduce power theft and save time and cost.

With the development of society, electricity consumption is increasing. This is a consequence of the saturation with appliances and the growing demands for personal comfort. Therefore, losses from electricity transmission are increasing and need to be studied in order to improve the quality of the power supply and to maintain optimal configurations of the electricity distribution networks. Energy theft is an important part of total losses. In the past, this was important in my country as well, but with the introduction of modern intelligent energy facilities, this part has been minimized. In this sense, I find the study of electricity consumption a topical issue [2-6]. Line loss rate is one of the important indicators to describe the power loss in the power grid. In the past, the research on the line loss rate was mainly focused on the middle and high pressure, and the research on the line loss rate in the low pressure area was less. The low-voltage area generally refers to the 220V and 380V power supply voltage area, which is often the area we live in, so this part of the study is closely related to us. However, due to the difficulty of data collection and confidentiality, there are few studies on actual data in this area. Previous studies have focused on calculating feeder line loss rates. For example, Shouxiang Wang et al. proposed the method of statistical line loss [7-8]. In this paper, in
addition to the analysis of electricity consumption, we also analyzed the loss of electricity, line loss rate, electricity supply and other factors, and explored their statistical rules.

2. Materials

2.1. Data Description and Preprocessing

2.1.1 Electricity data in the power supply area. In this article, the data came from a power company in western China. The original document covers a total of 566 power supply zones, spanning from June 1, 2016 to June 4, 2017. Parameters include the number of power supply area, electricity supply, electricity consumption, dates, are shown in Table 1. The data are preprocessed. Complete the missing part of the data. Power supply zones with more than 6 consecutive null values are deleted. After pretreatment, 395 stations were left.

| Examples of the data | Field name | Field description |
|----------------------|------------|-------------------|
| 3300006789           | TG_NO      | Area number       |
| 350.89               | ES         | Electricity supply in a area |
| 323.79               | EC         | Electricity consumption in a area |
| 2017-3-06            | DATA_DATE  | Date |

2.1.2 User's electricity data. We also collected data on users’ electricity consumption, including 100,000 users, over a three-year period from 2014 to 2017. Parameters include user ID, date, current energy value of the user, and energy used. The parameters are shown in Table 2.

| Examples of the data | Field name | Field description |
|----------------------|------------|-------------------|
| 97845                | CONS_NO    | user ID           |
| 2017-5-09            | DATA_DATE  | Date              |
| 1234.56              | KWH_READING| User's current energy value |
| 17.45                | KWH        | energy used       |

2.1.3 Line loss rate. There are multiple users under a power supply area. If there are users stealing power under a power supply area, the power loss of the power supply area will increase. Power loss = power supply-power consumption. So we calculate the line loss rate as a parameter. Line loss rate is a comprehensive indicator, and we abbreviated as LLR in this article. It is calculated from the electricity supply (ES) and electricity consumption (EC). The formula is as follows:

\[
LLR = \frac{ES - EC}{ES} \times 100\%
\]

3. Statistical law of power parameters

First, we calculated the mean of daily line loss rate in our study area. We collected power data from 566 power supply areas. After data preprocessing, 395 regions were left. The period is from June 1, 2016 to June 4, 2017. We describe their scatter plots and fitting curves. In order to show better fitting effects, polynomial fitting is selected, and several parameters of the polynomial are shown in Figure 1. We found that the line loss rate tended to decrease over time, especially in 2017. This is also in line with the fact that the economy will lose less electricity.
Then, we counted the probability density distribution of all daily line loss rate data in the region, which involved 130,000 data. The results are shown in figure (a) of figure 2. And what we find is that it's skewed. For further investigation, the probability density distribution of the logarithm of the daily line loss rate is calculated, which is shown in Fig. 2 (b). Figure B shows an approximate normal distribution. According to the characteristics of power law distribution, we know that all line loss rates in the study area approximately conform to the normal logarithmic distribution. The mean is 2.66 and the standard deviation is 0.91, which means the mean line loss rate is 2.66%.

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Figure 1. Scatter plot and fitting curve of Mean of daily line loss rate.

Figure 2. (a) the probability density distribution of all daily line loss rate data; (b) the probability density distribution of the logarithm of the daily line loss rate.

Figure 3. (a) the probability density distribution of all regional power supply; (b) the probability density distribution of all regional power used.
Similarly, we draw probability density distribution maps for electricity supply and electricity consumption, respectively. A and B are shown in Figure 3. And we find that they're also skewed. But it's different from the skewness of the LLR. To explore further, we plot the CCDF curve, in which the power law distribution is linear in the linearly logarithmic coordinate system. CCDF is a complementary cumulative distribution function, which is the sum of the probabilities of the continuous function for all values greater than $a$. The formula is as follows:

$$F(a) = P(x > a)$$

(2)

Where $x$ is a random variable, $F(x)$ is CCDF, $a$ is some number, and $p(x)$ is the sum of probabilities. The results of the probability density distribution are shown in figure (a) of figure 4. Therefore, we judge that their distribution is approximately exponential. This part of the data is based on the electricity consumption and supply of each region, and each figure is the daily sum of the electricity in the region. That is, the amount of electricity generated in each region is continuously and independently generated at a constant average rate, or perhaps due to the small amount of data.

Figure 4. (a) Complementary Cumulative Distribution Function of all power supply; (b) Complementary Cumulative Distribution Function of all power used data.

In order to judge the accuracy of electricity distribution, we conducted statistical analysis on the scale of users' electricity consumption. We made a log-log model with 1 million data of 100,000 users in 3 years. In log-log coordinate, the distribution of power used data shows power law distribution. This is different from the electricity consumption data of a region, but more in line with the laws of nature.

Figure 5. the distribution of users’ power used in log-log coordinate
4. Conclusion and Discussion
In this paper, we conduct statistical analysis on the power supply, power consumption and line loss rate of 395 power supply stations. Line loss rate is an indicator to describe electricity consumption. We found the following rules:

• We found that the line loss rate decreased over the course of a year. This shows that the utilization rate of electricity is higher and higher, in line with the law of economic operation.
• The overall distribution of line loss rate is approximately lognormal distribution. It shows that most of the values of the line loss rate are small, but there are a few that are large.
• Total daily electricity supply and electricity consumption in the power supply area approximately obey exponential distribution. This distribution shows that the total daily electricity still has some regularity.
• In terms of electricity consumption, a statistical analysis was made on the daily electricity consumption of 100,000 users in three years, and it was found that the electricity distribution of users was in line with the power law distribution. This distribution suggests that most electricity consumption is on a very small scale, and only a few on a very large scale.

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