A Line Loss Calculation Method Based on Big Data and Load Curve

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Abstract. In this paper, a new technique line loss calculation method based on load curve is presented. First, the data is preprocessed and the outliers are removed. Then the load curve is analyzed, and the load current per day is fitted by polynomial approximation method, and the load current curve is obtained by nine-order fitting. Considering that the current at different time points may affect the fitting of the data, time sequencing is carried out to improve the fitting accuracy. Then for the resistance calculation, the voltage difference between the platform side and the user side and the platform side current are used to calculate, avoiding the use of line length which is difficult to measure in practice. This method makes full use of the available power network data, rearranges it, calculates it according to the continuous load curve, and gets more accurate and reliable results.

1. Introduction
With the development of the national economy and the improvement of people's living standards, the demand for electricity continues to increase [1], and the problem of line loss management becomes more and more prominent. Abnormal phenomenon of line loss is frequent in the platform area, and the line loss is different at different load levels, and the situation in each region is very unbalanced [2]. Therefore, the one-size-fits-all definition of qualified line loss interval and the traditional method of manually checking anomalies under the existing mode bring great difficulty to the loss reduction work [3].

The user's stealing will directly affect the management line loss of the station area, but it has no influence on the technical line loss (i.e., fixed line loss and variable line loss), so the anti-stealing should first remove the technical line loss. Traditional methods for line loss calculation include voltage loss method and equivalent resistance method [4]. Methods of line loss calculation based on intelligent algorithm include artificial neural network, genetic algorithm, etc. [5]. The above algorithm is difficult to be applied in practice, and most parameters cannot be obtained in practice. For example, the line length cannot be accurately measured due to the complexity of the actual situation of the line, and the labor cost is high. However, with the development of power grid construction and collection technology of metering devices, more and more accurate data can be obtained than before [6]. Based on this, this paper proposes a method to calculate line loss using comprehensive data as far as possible.

2. Principle analysis
Line loss can be divided into technical line loss and non-technical line loss (also known as management loss) by nature. According to the characteristics of loss, line loss can be divided into variable loss,
constant loss and unknown loss. In the transmission and distribution of power network, a part of the power loss is related to the equipment parameters and load of the power network. The loss belongs to the normal loss of equipment operation is an inevitable part of the loss. This part of the loss can be obtained through the theoretical calculation of typical daily line loss, which is called technical loss, and is also called theoretical loss. Technology wear and tear is an unavoidable part of it. Non-technical wear and tear is caused by inadequate management and can be avoided.

Technical line loss quantity includes several aspects:
(1) The power loss generated by a power network of not less than 35kV;
(2) Electric energy loss generated by 6~20kV distribution network;
(3) The power loss generated by a low-voltage network not higher than 0.4kV;
(4) The electric energy loss of shunt capacitors, shunt reactors, adjustable cameras and voltage transformers and the electric energy used by station transformers;
(5) Power loss of HVDC transmission system (DC line, grounding system, converter station).

There are mainly four formulas for electric energy calculation, the specific formulas are as follows:

\[ W = Pt \] (1)
\[ W = UIt \] (2)
\[ W = I^2Rt \] (3)
\[ W = \frac{U^2}{R}t \] (4)

Where, \( W \) is electric energy, unit Joule, \( P \) is power, \( U \) is voltage, \( I \) is current, \( R \) is resistance and \( T \) is time.

The first two apply to all circuits, while the second two apply only to pure resistance circuits. Because the latter two methods mainly calculate the pure resistance in the circuit electrical energy into heat energy. In short, in a circuit where electrical energy is converted to composite energy, the third method of calculating electrical energy only calculates the energy converted from electrical energy to thermal energy. The third method is also Joule's law, and the formula is as follows:

\[ Q = I^2Rt \] (5)

Where, \( Q \) is electric energy, unit Joule, \( I \) am current, \( R \) is resistance, and \( t \) is time.

Joule's Law is a law that quantitatively describes the conversion of electrical energy into thermal energy by conducting current. The theorem is: the heat generated by the current through the conductor is directly proportional to the second square of the current, directly proportional to the resistance of the conductor, and directly proportional to the time of conduction. Therefore, joule's law is used to calculate the thermal energy loss in the technical line loss, which is approximately equal to the technical line loss. The calculation method of technical line loss in this paper is mainly used to calculate the conversion of electrical energy into thermal energy during transportation.

3. Calculation process and algorithm for estimating the technical line loss

3.1. The data source
The electricity consumption data of several users in the electricity information acquisition system are collected, and the data are stored in the central database through the data transmission channel and data receiving system as the data source of technical line loss calculation. The main data needed are total line loss, public transformer load and user load. The daily public variable load and user load are the real-
time data of the day in the electricity information acquisition system, with one data point every 15 minutes and a total of 96 data points in a day.

For the calculation of the total line loss in the station area, the difference between the power supplied and the actual power sold in the electricity information acquisition system is mainly used. Specific formula: line loss = power supply - sold power, power supply = factory power supply + input power + purchase power. Electricity sold consists of two parts, one is the non-electricity consumption supplied by the power enterprise to the enterprise, and the other is the electricity sold to the users.

3.2. Technical line loss calculation

(1) "I^2t" Calculation

The current of the public transformer load is not a fixed value. In the electricity information acquisition system, there is a public transformer load current point every 15 minutes. For the 96 current points in a day, the fitting curve is first performed, and then the square of the fitting curve is integrated. For current load Curve linear fitting of a day, using the MATLAB Curve Fitting Tool kit, using Polynomial fitting Polynomial approximation method, and then compared with 7, 8 and 9 order fitting results. The main comparison is whether the sum of error squares (SSE) is close to 0, whether the multiple measurement coefficient (R-square) is close to 1, whether the degree of freedom Adjusted R square (Adjusted R - square) is close to 1 and whether root mean square error (RMSE) is close to zero, and the final choice is the 9 th order fitting with good effect of each parameter. Integrate the resulting load curve for one day to get "I^2t". The formula is as follows:

\[ I^2t = \int_0^T I^2(t) dt \]  

(6)

Where, the unit of load current I is ampere (A), the unit of time t is seconds (s), and T represents 86400 seconds (s) of time of day. For three-phase circuits, phase A, phase B and phase C can be calculated separately.

(2) Calculation of resistance "R"

In the calculation of resistance, the resistance of the conductor is mainly calculated. The calculation formula of the resistance of the conductor is as follows:

\[ R = \frac{\rho L}{S} \]  

(7)

Where \( \rho \) represents the resistivity, \( L \) represents the length of the wire, and \( S \) represents the cross-sectional area of the conductor.

The length \( L \) of the wire can't actually be measured. Since there are still three phase voltage and three phase current data in the electricity information acquisition system, the following formula is adopted to replace them:

\[ R = \frac{\Delta U}{I} \]  

(8)

Where I represent the three-phase current in the public transformer load of the platform area, and the terminal voltage \( \Delta U \) is the difference between the three-phase voltage at the public transformer load on the side of the platform area and the three-phase voltage at the user side of the user load.

Each day there are 96 data points of voltage, corresponding to the time point to calculate the terminal voltage \( \Delta U \), namely the difference between the public transformer load and the three-phase voltage of the user load. The formula is as follows:

\[ \Delta U = U - U_0 \]  

(9)
Where, \( U \) is a term in the three-phase voltage of public transformer load, and \( U_0 \) is a term in the three-phase voltage of user load.

Similarly, the terminal voltage of the remaining two phases in the three phases is calculated.

The final 96 resistance values of a day are obtained by dividing the 96 voltage points of each phase in the three phases with the current of each term in the three phases corresponding to the public transformer load. Finally, the resistance value of a day is obtained by averaging the 96 resistance values. The calculation formula is as follows:

\[
R = \frac{U - U_0}{I} \tag{10}
\]

Where, \( U \) and \( I \) represent the three-phase voltage and three-phase current of the public transformer load, the unit is volt (V) and ampere (A), and \( U_0 \) is the three-phase voltage of the user load.

(3) Calculate the technical line loss method

Based on the method of "\( I^2Rt \)" and the "\( I^2t \)" and "\( R \)" obtained by calculation, the loss of technical line loss per day is calculated and divide by 360,000 conversion units, joule conversion to kilowatt hours (kw.h), the formula is as follows:

\[
W = \frac{R \int I^2(t) dt}{3600000} \tag{11}
\]

\[
R = \frac{U - U_0}{I} \tag{12}
\]

Where, \( I^2(t) \) is the current load curve, \( T \) represents the time of day 86,400 seconds (s), \( U \) and \( I \) are the voltage and current of the public transformer load, and \( U_0 \) is the voltage of the user load. The specific process is shown in the figure below.

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**Fig. 1** Calculation flow of technical line loss

**Fig. 2** Calculation flow of load curve
4. Case Analysis and Discussion

The real data of platform area A in Zhejiang province was selected for analysis, and the data required for collection are each platform area's total line loss, public transformer load and user load. Part of the data is shown in Table 1 and Table 2 below.

| Tab. 1 Power consumption and loss of platform area A |
|-----------------------------------------------------|
| Platform Area ID | Date     | Power Supply | Power consumption | Loss of power |
| 7684790          | 20170101 | 2551         | 2460              | 91            |
| 7684790          | 20170102 | 2531         | 2442              | 89            |
| 7684790          | 20170103 | 2603         | 2508              | 95            |
| 7684790          | 20170104 | 2502         | 2416              | 86            |
| 7684790          | 20170105 | 2660         | 2569              | 91            |

| Tab. 2 Data of public transformer load of platform area A |
|----------------------------------------------------------|
| Platform Area ID | Date     | A phase voltage | A phase current | B phase voltage | B phase current | C phase voltage | C phase current |
| 7684790          | 2017/1/1 0:00 | 230   | 1.8        | 230   | 1.9        | 231   | 1.76        |
| 7684790          | 2017/1/1 0:15 | 230   | 1.8        | 230   | 1.9        | 231   | 1.75        |
| 7684790          | 2017/1/1 0:30 | 231   | 1.74       | 231   | 1.83       | 232   | 1.69        |
| 7684790          | 2017/1/1 0:45 | 231   | 1.51       | 231   | 1.61       | 232   | 1.46        |
| 7684790          | 2017/1/1 1:00 | 231   | 1.7        | 231   | 1.8        | 232   | 1.65        |

First, the three-phase current in the public transformer load is fitted at 96 points per day, and the fitting situation of phase A current is shown in Figure 3. Then the current squared is integrated. Finally, the technical line loss is calculated on the basis of equivalent resistance. The technical line loss is shown in Figure 4.

Fig. 3 Fitting of the phase A current of the public transformer load in platform area A on January 1st, 2017
For line loss rate, there is the original line loss rate and the line loss rate after stripping the technical line loss. The original calculation formula of line loss rate is as follows:

Original line loss rate = (power supply - power consumption)/power supply

The calculation formula of line loss rate after stripping technical line loss is as follows:

Line loss rate after stripping technical line loss = (power supply - power consumption - technical line loss)/power supply

The calculation results of specific line loss rate are shown in Figure 5. Figure 6 shows the power supply of the platform area. According to the relative ratio of the two-line loss rates in Figure 5 and the power supply in Figure 6, it is found that the higher the power supply, the higher the proportion of technical line loss, which is consistent with the actual situation and shows that this method has a certain degree of rationality.
Figure 7 shows the daily electricity consumption data of a certain power theft user in platform area A in Zhejiang province from January 1st to February 24th, 2017, and Figure 8 shows the daily electricity consumption data of a certain power stolen user in platform area A in Zhejiang province from January 1st to February 24th, 2017. Pearson correlation coefficient is calculated between electricity consumption and two-line loss rates respectively. Figure 7 shows the data of power theft users, and the correlation coefficient with the line loss rate is -0.14600411, and the correlation coefficient with the line loss rate after stripping the technical line loss is -0.47479852. It can be seen that the correlation coefficient of power theft users decreases. Figure 8 shows the data of a normal user, and the correlation coefficient with the line loss rate is -0.00051011, and the correlation coefficient with the line loss rate after stripping the technical line loss is 0.07662592, indicating that the correlation coefficient of a normal user is increased. Pearson correlation coefficient of more user are shown in Table 3. To sum up, the two types of users present opposite situation, which can be taken as a factor in the research of anti-electric larceny, but it is not a decisive factor, and needs to be analyzed in combination with the characteristics of electric larceny users. However, this method has made a certain breakthrough in the research of anti-electric theft.

![Fig. 7 Daily electricity consumption of the electric-theft user 3518671877](image1)

![Fig. 8 Daily electricity consumption of normal user 3518671767](image2)
### Tab. 3 User Pearson correlation coefficient changes

| User ID         | Pearson correlation coefficient between electricity consumption and original line loss rate | Pearson correlation coefficient between electricity consumption and line loss ratio with technical line loss removed |
|-----------------|-------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------|
| 61181 47969     | 0.02102562                                                                                     | -0.17313198                                                                                           |
| 61181 47984     | -0.05356849                                                                                     | 0.02008976                                                                                           |
| 61181 47989     | 0.37012013                                                                                      | -0.07640047                                                                                           |
| 61201 50766     | -0.21025130                                                                                     | 0.05839810                                                                                           |
| 61181 47943     | 0.02032143                                                                                      | 0.03986721                                                                                           |
| 61181 38899     | -0.22222222                                                                                     | 0.31985978                                                                                           |
| 61181 38871     | 0.03032105                                                                                      | 0.25071135                                                                                           |
| 61110 34747     | 0.11111111                                                                                      | 0.38220636                                                                                           |
| 61181 38833     | 0.00103201                                                                                      | 0.23467193                                                                                           |
| 61181 38922     | 0.11111111                                                                                      | 0.14182165                                                                                           |
| 61181 38824     | 0.11111111                                                                                      | 0.37151157                                                                                           |
| 61181 36664     | 0.00201305                                                                                      | 0.03845170                                                                                           |
| 61181 39628     | 0.37521035                                                                                      | 0.07475495                                                                                           |
| 61110 94036     | 0.12521304                                                                                      | 0.28551579                                                                                           |
| 61181 38933     | 0.11111111                                                                                      | 0.17092354                                                                                           |
| 35186 71877     | -0.14600411                                                                                     | -0.47479852                                                                                          |
| 35186 71767     | -0.00051011                                                                                     | 0.07662592                                                                                           |

Note: If the font is bold, it is the user stealing electricity. If the font is not bold, it is the normal user

### 5. Conclusions

This paper presents a new method of line loss calculation based on load curve. The method is verified on the basis of real data cases and analyzed in combination with field queries. This method is analyzed by multiple methods, such as load curve, polynomial linear fitting, current point integral, terminal voltage instead of voltage, etc, which break through the existing shortcomings of the technology of line loss calculation method cannot achieve and parameter cannot actually receive. It can make full use of the relevant departments of the existing data to calculate the technical line loss more effectively. In addition, future work needs to integrate more basic algorithms into this method from more angles to improve the effectiveness and stability of this method.
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