Research on Key Techniques for Negative Line Loss Rectification of Interprovincial Transmission Lines

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Abstract. Carry out in-depth research on the causes, mechanisms, and key remediation technologies of abnormal line losses across transmission lines, study transmission line loss and line impedance, network topology, line flow, line insulation, corona discharge, environmental temperature and humidity conditions, and measurement devices relationship between influencing factors such as errors. Establish a theoretical model of the multi-parameter error influencing factors of line loss under special conditions of inter-provincial transmission line routes. Based on the causes and mechanisms of abnormal line losses, research and propose efficient and comprehensive management methods and techniques for negative line losses. The lean management and evaluation system lays the technical foundation.

1. Introduction

Line loss management is a basic technical task, which is an urgent need for the daily production and assessment indicators of the power grid. Abnormal line losses will cause the line loss system to fail to analyze normally during the same period. Come great obstacles. Secondly, improving the level of loss management of transmission lines can guide the safe and economic operation of transmission lines and power grid equipment, and improve personal safety and the level of power grid equipment operation. The trans-provincial transmission line transactions are huge, and its line loss management work is particularly important. The accuracy of settlement power is related to the economic interests of various transaction entities. The abnormal line loss phenomenon will not only make the accuracy and fairness of the pass measurement doubtful, but also extremely easy Trade settlement issues and even legal disputes arise.

As an important technical and economic indicator of power supply companies, line loss rate has a huge impact on the development of power companies. The solution to the problem of abnormal line loss has certain guiding significance for power grid planning and design, energy conservation and loss reduction, and it can make more reasonable use of resources and increase business operating profits. Studying the line loss mechanism can provide a theoretical basis for line loss management, promote technical specifications for the selection of gateway metering devices, and can quickly locate the cause of line loss anomalies, support the cross-province transmission line negative line improvement project, and improve the effectiveness of rectification.
2. Establishment of theoretical line loss model for transmission lines

Influencing factors of multi-parameter error of line loss under special conditions of inter-provincial transmission line routes. The research method is to round it to zero. The overall idea is to decompose the transmission line route loss model into a theoretical line loss model and a measurement system error model.

The theoretical line loss model is the inherent power loss in the normal operation of the transmission line. It is the lower limit of the line loss. According to the data collected at the beginning of the project, this part mainly includes the overhead line loss model and the reactor loss model. The measurement system error model includes the transformer error, the energy meter error, and the timing error. This part of the model reflects the additional loss above the theoretical line loss in actual working conditions, which is an important component of the upper limit of the actual line loss.

The variables that affect the above model, that is, special working conditions mainly include parameters such as transmission power, power flow direction, load distribution, temperature and humidity, and electromagnetic environment. Each parameter and two models are integrated to establish a multi-parameter cross-province transmission line route loss model. The schematic diagram of the power line route loss model is shown in Figure 1.

![Figure 1. Schematic diagram of theoretical transmission line loss model.](image)

The operating conditions of inter-provincial transmission lines mainly include the characteristics of large fluctuations in transmission power, rapid changes in the direction of power flow, large transmission power differences on the same tower double circuit line, long line distances, and large changes in temperature and humidity. Therefore, it needs to be based on the basic loss model. Targeted improvement, the method of describing the characteristic quantity of the inter-provincial transmission line is studied, the typical value of the characteristic quantity is extracted, and the power loss model of the transmission equipment including multiple factors is studied.

3. Theoretical Model of Line Loss under Operating Conditions

AC 500kV inter-provincial transmission lines generally use overhead transmission lines, and the length of the line generally does not exceed 300km. High-voltage reactors and other equipment are installed on one side of the transmission line for reactive power compensation. According to the electrical network theory, Π-type equivalent circuits can be used for AC overhead transmission lines below 300km, as shown in Figure 2.
Reactor losses are directly related to line voltage, while transmission line losses are related to both line and line voltage. The line voltage fluctuation on the transmission line is generally not too large, and the fluctuation of the transmission power may be obvious. Therefore, the loss value on the reactor is generally stable, and the loss fluctuation on the transmission line is relatively large with power. When the line load is relatively small, the change of the reactor loss value is small, and the line loss rate is relatively large at this time.

In actual operation, all kinds of electric energy data are obtained through metering devices such as electric energy meters, current transformers and voltage transformers on both sides. At present, only explicit accuracy requirements are generally imposed on individual measurement devices, and there are no specific requirements for comprehensive errors. Therefore, adding the consideration of the measurement error of the measurement device to the theoretical line loss model will make the result more accurate and the reference value higher. After research, it is found that the parameters that have a significant effect on the line loss are mainly the measurement errors and timing errors of the measuring devices on both sides. FIG. 3 is a solution block diagram of a multi-parameter modified statistical line loss model.

First calculate the load flow through the line structure parameters and operating data, and add corrections for temperature, corona, and overhead ground lines. The measurement errors of the measurement devices at both ends and the analysis of the data of the measurement devices are used to synthesize the measurement errors. Based on the calculation of the theoretical model, the measurement errors and timing errors are added to the line loss model to correct them.

4. Causes of negative line loss in interprovincial transmission lines

4.1. Transmission line load rate is too low
With the current construction and development of the power grid, the power grid is becoming stronger and stronger, and the load rate of inter-provincial transmission lines is at a relatively low level during normal operation. For inter-provincial transmission lines, the rated transmission load is generally
around 500,000 Kw to 2 million Kw, but the actual operating load of the line is often only tens of thousands of Kw or less.

When the line load rate is low, the main causes of negative line loss are: the current transformer measurement error increases under low load; the current transformer measurement error increases under low load; the transmission line is at zero or In its critical state, theoretically there will be an extreme case where both ends of the line provide power loss to the line at the same time. In this state, a slight offset may cause negative line loss.

4.2. Unreasonable energy metering device configuration
The comprehensive error $\varepsilon$ of the energy metering device is the sum of the error $\varepsilon_w$ of the energy meter, the combined error $\varepsilon_h$ of the transformer error, and the combined error value $\varepsilon_r$ of the secondary circuit, which can be expressed by the following formula:

$$\varepsilon = \varepsilon_w + \varepsilon_h + \varepsilon_r$$

Where: $\varepsilon_w$ is the error of the energy meter, $\varepsilon_h$ is the combined error of the ratio difference $f_I$ and angular difference $\delta I$ of the current transformer, the ratio difference $f_U$ and angular difference $\delta U$ of the voltage transformer, and $\varepsilon_r$ is the secondary circuit ratio difference $f_r$ The composite error of the angular difference $\delta r$.

Because there are electric energy meters, voltage transformers and current transformers, and secondary voltage drops of the transformers at both ends of the line, if the accuracy of all measuring devices meets the 0.2S accuracy requirement, if the measurement error at the sending end is negative, the receiving end will be negative. The measurement errors are all positive, and negative line loss in measurement may occur. Because the operating load of the inter-provincial transmission line is under low load for a long time, the theoretical line loss rate is concentrated in the range of 1% to 3%, causing measurement errors to cover the line loss and thus generate statistically negative line loss.

4.3. Power cut off error
Because the internal code data of the energy meter is large, in order to avoid data overflow, the uploaded data needs to be converted and saved with a fixed accuracy. The conversion ratio is generally set according to the line load level. If a large conversion ratio is used when the line load level is low, a large error will occur in the statistical power data. The statistical power expression is:

$$W = \left( \left| \frac{p_2}{b} \right| - \left| \frac{p_1}{b} \right| \right) \times b$$

In the formula, $W$ is the statistical power data, $b$ is the conversion ratio, $p_2$ and $p_1$ are the end table code and the start table code before the conversion, respectively, and represent the decimals with a fixed number of digits. Because the start table code, end table code, and transmission power of a certain period of time change randomly, the actual statistical error caused by the power upload protocol fluctuates within the range of $0 \sim \varepsilon_{\text{max}}$. $\varepsilon_{\text{max}}$ is the maximum value of the battery error.

4.4. Out-of-tolerance or unreasonable selection of power metering device
Due to the limitation of detection conditions of power transformers, it is not possible to perform field operation error tests several times a year, and its measurement performance is difficult to judge. CVT’s operating reliability is low, and various performance degradations occur after a short period of installation and operation.

Transformer capacity configuration is too large, affecting accuracy. As the pass energy meter is a fully electronic multi-function energy meter and the working power supply is independently powered, the actual load after field testing is less than 1VA. The mismatched configuration of the rated load of the transformer and the actual makes the measurement accuracy impossible.
4.5. Clock error causes negative line loss
The negative line caused by the clock error of the energy meter at the sending and receiving ends, the sending end clock is \( \Delta t \) slower than the receiving end clock. The energy received by the receiving end during \( t_0 - t_1 \) is:

\[
W_{\text{receive}}^1 = P_1 \cdot (t_1 - t_0)
\]  

(3)

At the same time, the power sent by the sender is:

\[
W_{\text{delivery}}^1 = (P_1 - P_1^{\text{loss}}) \cdot (t_1 - t_0 - \Delta t) + (P_2 - P_2^{\text{loss}}) \Delta t
\]  

(4)

Therefore, the line loss in the period \( t_0 - t_1 \) is:

\[
\Delta W = W_{\text{delivery}}^1 - W_{\text{receive}}^1 = (P_2 - P_2^{\text{loss}}) \Delta t - P_1^{\text{loss}} \cdot (t_1 - t_0 - \Delta t) - P_1 \Delta t
\]  

(5)

Obviously, \( \Delta W \) is negative, so the line appears negative line loss because the clocks at both ends are not synchronized.

5. Negative line loss remediation method for interprovincial transmission line routes

5.1. Transmission line load rate is too low to rectify
The main method to rectify the negative line loss caused by the low load rate of the transmission line is to reasonably adjust the transformation ratio of the current transformer to make the measuring equipment work at the rated working conditions as much as possible. When designing, generally set the operating transformation ratio of the line current transformer according to the line safety protection, and the transformation ratio of the measurement winding is the same as the protection. Because the technical requirements of the protection ratio often take the large ratio of the transformer, but it has an impact on the accuracy of the metering winding. In order to improve the measurement accuracy of current transformers across inter-provincial transmission lines and make the measurement windings work in a better state, it is necessary to reduce the transformation ratio reasonably according to the situation.

5.2. Unreasonable Rectification of Energy Metering Device Configuration
The configuration of the power metering device at the gate of the transmission line is unreasonable. The main rectification methods are: make the voltage transformer, current transformer, secondary voltage drop of the voltage transformer, and energy meter. The error of each part tends to zero, and the comprehensive error can tend to zero. The error coordination between the components of the gateway energy metering device makes the comprehensive error tend to zero.

5.3. Rectification of power truncation error
In the inter-provincial transmission line gateway metering devices, the energy meters use high-quality energy meters with high accuracy and stability. The number of digits after the decimal point is usually 4 digits, but the number of digits after the decimal point in some provinces and cities’ energy collection systems is only set. Three. Therefore, for the rectification of the truncation error of electric energy, the provinces and cities need to have a unified technical standard, and the number of digits after the decimal point of the electric energy collection system is set to 4 digits. In addition, lengthening the statistical period of the line loss can also reduce the influence of the power truncation error.
5.4. Clock Error Causes Rectification of Negative Line Loss
The error of the energy meter clock will cause different periods of power collection, which will cause negative values of statistical wire loss. The main improvement method is to strengthen the time management of the energy meter and synchronize the energy meter clock with the standard clock. The main reason for the clock error is the lack of broadcast time calibration principles and communication protocols, which can be improved by studying the corresponding communication protocols. Study the new technology of time synchronization for electric energy meters, and change the broadcast time synchronization mechanism of traditional collection terminals.

6. Conclusion
Through the establishment of the theoretical model of the multi-parameter error influencing factors of line loss under special conditions of interprovincial transmission line routes, the effect of loss on the transmission line under actual operating conditions is studied, the formation mechanism of abnormal line losses is analyzed, and the theoretical line loss of transmission lines is improved. The calculation method provides theoretical basis for accurate measurement, reasonable evaluation and effective management of line loss. Improve the basic data quality of the company’s simultaneous line loss management system, and improve the accuracy of line loss measurement, analysis and calculation. A comprehensive treatment plan for abnormal line loss of transmission lines is proposed to provide technical guidance for comprehensive treatment of abnormal line losses of inter-provincial transmission lines.

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