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Energy Saving Measurement Methods in Power Grid Engineering

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Abstract. In this paper, we focus on the issue of energy-saving measurement processes and confirmation methods, and combines energy-saving quantitative analysis of power-saving projects to provide reference for energy-saving audits of power-saving projects in the future. We have designed energy efficiency assessment programs and processes, and designed a number of energy-saving test program methods based on different businesses, environments, and projects, including energy-saving measurement methods for power line reconstruction, energy-saving measurement methods for transformer replacement, and energy-saving measurement for reactive power compensation reconstruction. The method has been applied to the power-saving calculation of the energy-saving project of the power grid itself, providing a theoretical calculation basis for the power grid enterprise to complete the energy-saving target.

1. Introduction
The power system itself is a large energy consumer, and the distribution network is the main part of the energy loss of the power system. Realizing the energy saving and consumption reduction of the distribution network plays a decisive role in improving the economic benefits and reducing the environmental pollution of the power supply enterprise. Therefore, the energy-saving technology that realizes the energy-saving and consumption-reducing of the distribution network has become the focus of research in recent years, and has also been widely applied to practical applications. However, how to evaluate the energy-saving effect of the distribution network, how to more specifically improve the energy-saving level of the distribution network, which will become an urgent problem to be solved in the process of energy-saving technology development. In view of this, it is imperative to form a reasonable, scientific, systematic, and perfect distribution network energy-saving index and power-saving calculation method. Studying distribution network energy-saving indicators and energy-saving calculation methods will help the development of energy-saving and loss-reduction technologies for distribution networks.
Usually, the energy-saving and loss reduction in the power grid can be divided into two aspects: saving power and saving electricity. The meaning of the two is different. Power saving refers mainly to power savings in units of \( kW \), while power savings are savings in electrical energy in units of \( kWh \). For users, power saving is the focus of attention, because it is directly related to the economic interests of users. For the power companies, both are equally important. Saving electricity can reduce the loss of the power grid, increase the power transmission capacity, and reduce economic losses. In addition, energy-saving power represents the degree of demand for electrical energy, and the reduction in user demand can enable power companies to meet the already-high and possibly rising peak load without investing in capacity expansion. This reduces investment costs and avoids additional losses caused by new equipment in the grid.

In this paper, we focus on the energy saving measurement methods in power grid engineering. First, the measurement and verification process was designed. Secondly, measurement methods were designed for power line reconstruction measurements, transformer replacement measurements, and reactive power compensation measurements.

2. Measurement plan and process
Measurement and verification (M&V) is an important technical guarantee link in the energy-saving transformation of power grids. Regular measurement and verification can effectively monitor the energy-saving amount, and can timely adjust the energy-saving renovation program through changes in data to ensure energy-saving benefits. Because there are many uncontrollable factors in the actual process, such as weather, temperature, and unconventional human factors all affect the baseline value of the loss, adjustments for these effects are usually required to include routine adjustments and non-regular adjustments. The amount of energy saved after the power grid is transformed and the maximum load that can be reduced can be determined by the amount of electricity and the load before and after the implementation of the project, as follow:

\[
\text{Energy savings} = \text{base annual energy consumption} - \text{energy consumption after retrofitting}
\]

A complete set of energy efficiency assessment process includes pre-evaluation and post-evaluation. The main procedures are as follows:

1) Demarcate the boundaries and conditions of energy-saving renovation projects;
2) Determine the project measurement and verification program;
3) Measure and collect equipment power consumption and average power consumption data during the typical working period of the base period and analyze the records;
4) Pre-assessment report of energy-saving renovation projects;
5) Measure and collect data on equipment power consumption and average power consumption during the typical working period of the reporting period, and analyze records;
6) Calculate the project to save electricity and electricity, and make corrections as needed, and write a project to save electricity power verification report.

And the process is as Figure 1:

Since the reference value after implementing the energy-saving transformation of the grid cannot be obtained through actual measurement, the method based on the verification simulation can calculate the reference value with a certain degree of accuracy quickly and easily, thus showing a strong superiority. Based on the calibration simulation method, the loss reduction of the energy-saving transformation of the power grid can be clarified. After the energy-saving transformation of the power grid is implemented, the reference value cannot be obtained through actual measurement, and the superiority of the calibration simulation model method is fully reflected.
Figure 1. Measurement and verification flow chart.

3. Measurement methods

3.1. Measurement for power line reconstruction energy saving

The total power loss $\Delta P_L$ of power supply and distribution system lines includes ground conduction loss $P_C$ and line load loss $P_R$. Since the line-to-ground conductance loss is mainly caused by insulator leakage and corona, when the user's power supply voltage is 110$kV$ or below, it can be ignored. Processing: line loss generally refers to the line load loss, which is related to the ampacity, operating voltage, line model, transmission distance and distribution along the load. The power circuit (i-j) that needs to be modified is shown in Figure 2.

Figure 2. The power line equivalent circuit for reforming.

As the line-to-ground conductance loss is mainly caused by insulator leakage and corona, it can be neglected in the low- and medium-voltage lines (35$kV$ and below); the line loss in the low-voltage distribution network generally refers to the line load loss, and its current carrying capacity, the operating voltage, line model, transmission distance, and load distribution along the line, the mathematical expression is as follow:
\[ \Delta P_l = 3I^2R = \frac{P^2}{U^2\lambda^2}\rho l/A \]  

(1)

3.2. Measurement for transformer replacement energy saving

In view of the parameters involved in the transformation of power transformers, the following project energy saving tests and calculation plans has been formulated. The equivalent circuit of the power transformer that needs to be modified (in double loops as an example) is shown in Figure 3.

\[ \begin{align*}
\text{Figure 3. The transformer } \Gamma \text{ type equivalent circuit diagram for reforming.}
\end{align*} \]

Transformer total power loss \( \Delta P_T \) includes iron loss \( P_{Fe} \) and copper loss \( P_{Cu} \) in two parts:

\[ \Delta P_T = P_{Fe} + P_{Cu} = \left(\frac{U}{U_N}\right)^2 P_0 + \left(\frac{P}{S_N\lambda}\right)^2 P_k \]  

(2)

where:

- \( P_{Fe} \) - Eddy current loss of the excitation branch;
- \( P_{Cu} \) - The resistance loss of the transformer coil.

From the formula, it can be seen that the influence factors of the factors that affect energy consumption and the different stages of the planning and construction of the power supply and distribution system.

Table 1. The Influence of Each Energy Consumption Factor of Transformer in Power Distribution System and the Example of Loss Reduction.

| Impact factor          | Relationship                  | Energy Savings Reduction Example                                               |
|------------------------|-------------------------------|-------------------------------------------------------------------------------|
| No-load loss \( P_0 \) | Fixed loss                    | Roll core, amorphous alloy and other high-type transformer application        |
| Load loss \( P_k \)    | Proportion                    | Original low-type aluminum wire transformer was transformed into copper wire transformer |
| Rated capacity \( S_N \) | Copper loss is inversely squared, and iron loss is basically a proportional relationship. | When the transformer is selected to allow it to operate in the economic load rate range |
| Load \( P \)           | Squared proportional          | Load balance of each transformer, demand side management such as peak load and valley fill |
|                        |                               | To balance the load of each period, try to make the transformer load rate run at |
Comparing the total loss of the transformer with the transformer load, the loss rate in transformer operation can be obtained:

$$\frac{\Delta P_T}{P} = \left(\frac{U}{U_N}\right)^2 P_0 + \left(\frac{S}{S_N}\right)^2 P_k = \frac{1}{\lambda}\left(\left(\frac{U}{U_N}\right)^2 P_0 + \frac{SP_k}{S_N}\right)$$  \hspace{1cm} (3)

The transformer has the lowest loss rate if and only if the constant losses and variable losses in the operation of the transformer are equal. At this time, the economic load rate of the transformer is:

$$\beta = \frac{P_0}{P_k}$$  \hspace{1cm} (4)

In the transformer selection, the main consideration should be given to the transformer's capacity selection: if the transformer capacity is too small, it will cause too much copper loss; conversely, if the capacity is too large, it will increase the iron loss accordingly. Therefore, according to the transformer need to supply the load, according to the transformer's economic load rate to push back the rated capacity; power supply system is part of the transformation of energy-saving loss reduction of the important content.

3.3. Reactive power compensation reconstruction energy saving measurement

Reactive power compensation can be roughly divided into the following four ways:

1) **Substation centralized compensation**: To balance the reactive power of the transmission grid, centralized compensation can be performed at the substation. In this way, the compensation device includes a parallel capacitor, a synchronous camera, a static compensator, etc., but parallel capacitors are usually used in the distribution network, and the capacity is in the MVar class. The main purpose is to improve the power factor of the transmission network and increase the terminal voltage. The compensation device is generally connected to the 10kV bus in the substation. The advantage is that the management is easy and the maintenance is convenient; the disadvantage is that it does not have any effect on the loss reduction of the distribution network.

2) **Distribution and low pressure centralized compensation**: Another reactive power compensation method that is commonly used in China is to perform centralized compensation on the 380V side of distribution transformers. According to the fluctuation of the user's load level, input a corresponding number of capacitors for tracking compensation. This compensation method is beneficial to ensure the user's power quality, but its compensation size will change with the line voltage fluctuations.

3) **Line reactive power compensation**: Line reactive power compensation, also known as reactive power compensation on the pole. If there is a distribution transformer without reactive power compensation in the distribution network, or if the distribution line is too long and the reactive power loss of the line is high, in order to avoid the transmission of a large amount of reactive power along the line, it is possible to install on the tower of the overhead line. The pole reactive power optimization compensation must be performed in conjunction with the following actual engineering requirements.

4) **User terminal decentralized compensation**: User terminal decentralized compensation mainly refers to the method of direct compensation at the low-voltage user's terminal. The user terminal dispersion compensation method can effectively reduce line loss and voltage loss, improve voltage quality, release system energy, and improve line power supply capability. The disadvantage is that the
utilization rate of the equipment is not high, and the feasibility of implementation is not high for a user terminal of a cell with small load, large fluctuations, scattered locations, and no management.

4. Conclusion

In this paper, we focus on the issue of energy-saving measurement processes and confirmation methods, and combines energy-saving quantitative analysis of power-saving projects to provide reference for energy-saving audits of power-saving projects in the future. We have designed energy efficiency assessment programs and processes, and designed a number of energy-saving test program methods based on different businesses, environments, and projects, including energy-saving measurement methods for power line reconstruction, energy-saving measurement methods for transformer replacement, and energy-saving measurement for reactive power compensation reconstruction method. The method has been applied to the power-saving calculation of the energy-saving project of the power grid itself, providing a theoretical calculation basis for the power grid enterprise to complete the energy-saving target.

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