Research on Power Quality Evaluation Method for High Energy-consuming Enterprises

Yu Liu*, Junde Liu², Bo Yang³, Liaoyi Ning⁴, Xiangbo Zhu⁵, Xue Wang⁶, Shenghua Bian⁷

¹,²,³,⁴,⁵,⁶,⁷ State Grid Anshan Electric Power Supply Company, Liaoning, China

*Corresponding author e-mail: 1027383287@qq.com

Abstract. With the increase of the voltage level of the power system, the demand for electric energy of high energy-consuming enterprises continues to increase, which puts forward higher requirements on the power quality. As power quality problems become more and more prominent, how to manage power quality scientifically and reasonably has attracted more and more attention from power quality workers. At the same time, users have increased their power quality requirements and the continuous development of power marketization. To achieve comprehensive power quality management, it is necessary to have a scientific, accurate, and standardized assessment of power quality. In-depth understanding and understanding of power quality, attach great importance to the harm and impact of power quality degradation on the operation of the power supply system, and it is particularly urgent to achieve comprehensive power quality management.

1. Introduction

With the deepening of the informatization and intelligence of the power grid, power quality monitoring has evolved from single-point monitoring in the past to system monitoring now, and a complete power quality monitoring system framework has been gradually formed. Due to the rapid development of monitoring systems, the scale of data is increasing day by day, and exploring fast and intelligent power quality data analysis and processing methods has become an important issue that needs to be solved urgently. Correctly assessing the economic cost of power quality and proposing an economical and reasonable governance plan can not only improve the production management of users, power companies, equipment manufacturers and other participants, increase economic benefits, but also have important significance for energy conservation and alleviation of energy crisis. By strengthening power quality management, the power loss and economic loss on the demand side can be reduced, and the goal of power demand side management can be fully realized.

In recent years, artificial intelligence represented by machine learning has continued to develop, such as deep learning, reinforcement learning, etc. The application of new methods to solve traditional power quality disturbance recognition continues to expand, and with the increase of power quality monitoring data, based on artificial intelligence algorithms More exploration has been carried out by mining power quality disturbance monitoring data information, and good results have also been achieved. Literature [1] combines power quality research issues with the development of artificial intelligence algorithms, and sorts out some ideas about artificial intelligence algorithms in solving power quality problems. Literature [2] pointed out that power quality problems will bring huge economic losses to users, leading to reduced management efficiency and energy waste, and proposed a basic framework for power quality economic analysis. Literature [3-6] gives the relevant standards for various evaluation indexes of power quality.
quality, and establishes a power quality evaluation system suitable for nonlinear loads. Literature [7] uses the power information integrated management system to complete the 24-hour information monitoring and control of the five indicators of power quality by the power grid, and realizes online real-time monitoring and management of harmonic loads. Literature [8] proposed a method of using electricity information to collect data to analyze power quality. According to the severity of power quality at different times, a power quality management plan was formulated to refine the power quality management work.

2. Power quality evaluation indicators and weight determination

2.1. Power quality indicators

Any kind of product has its quality index, and electric energy also has a certain quality index. Only when the electric energy sent to the user meets the quality index can it exert its best benefits. However, due to the different perspectives of people's thinking, there is still no accurate definition of the technical meaning of power quality. From a practical point of view, this article analyzes the power quality in detail and breaks it down into the following categories:

(1) Voltage deviation

In the power system, the voltage deviation is defined as the ratio of the difference between the rated voltage and the actual voltage to the actual voltage value. In the actual operation of the power system, if the voltage deviation is unqualified, it will have many negative effects on industrial and agricultural production and people's lives. If the voltage is not effectively controlled, it may even cause the system voltage to collapse, cause a large-scale blackout, and cause huge economic losses. The calculation formula is as follows:

\[ \Delta U = \frac{U_s - U_N}{U_N} \times 100\% \]

In the formula: \( U_s \) represents the actual voltage value, \( U_N \) represents the rated voltage value.

(2) Voltage sag

Generally, the ratio of the mean square value of the voltage when the sag occurs to the mean square value of the nominal voltage is the amplitude of the voltage sag. The voltage sag is currently the most serious and concerned indicator of power quality.

(3) Three-phase unbalance rate

The three-phase unbalance rate can be expressed as the ratio of the maximum deviation of the three-phase voltage to the average value of the three-phase voltage. It can also be defined from the symmetrical component method, which is the percentage value of the root mean square value of the negative sequence component of the voltage and the root mean square value of the positive sequence component of the voltage.

(4) Voltage fluctuation

Voltage fluctuation is manifested as a rapid change in voltage value or a continuous voltage deviation phenomenon, and its change period is larger than the power frequency period. The ratio of the difference between the maximum value and the minimum value of the changing voltage mean square value to the rated voltage is the mathematical description of voltage fluctuation:

\[ \delta U = \frac{U_{max} - U_{min}}{U_N} \times 100\% \]

In the formula: \( U_{max} \) represents the maximum value of the mean square value of fluctuating voltage, \( U_{min} \) represents the minimum value of the mean square value of fluctuating voltage, and \( U_N \) represents the rated voltage value.

(5) Voltage flicker

Because the voltage fluctuation of the light source makes the illumination of the lamp unstable, the process of inducing the visual response of the human eye is voltage flicker. It is one of the harmful
consequences caused by voltage fluctuation and a subjective reflection, which does not belong to the category of electromagnetic phenomena.

(6) Voltage harmonics

Harmonics are sine components whose frequency is an integer multiple of the fundamental frequency, and sine components whose frequency is not an integral multiple of the fundamental frequency are called fractional harmonics or interharmonics.

(7) Frequency deviation

Frequency is the reciprocal value of the period. The difference between the actual frequency value and the power frequency value of the power system is the frequency deviation, which is expressed mathematically as follows:

\[ \delta f = f_s - f_N \]

In the formula: \( f_s \) represents the actual frequency value, \( f_N \) represents the power frequency value.

(8) Power supply reliability

Power supply reliability can be considered as a reflection of the power system's uninterrupted provision of power and electrical energy that meets the power quality standards and the amount required by the system to the power user. It reflects the power's satisfaction limit and importance for the development of the national economy.

(9) Evaluation of power supply serviceability

Electricity supply is a service behavior, and improving service quality is an important measure to optimize industrial structure and improve people's satisfaction. The service index is the quantitative evaluation through the evaluation of the power supply service by the power user.

2.2. Determine the weight of quality evaluation indicators

This paper proposes a method based on the minimum error of the power quality standard evaluation sample to determine the weight value of each indicator of power quality, which is called the minimum standard error weighting method. The specific steps are as follows:

1) Based on the power quality evaluation standard indicators, use the unifrnd function to randomly generate \( n \) uniformly distributed power quality data within each indicator interval of each power quality level to form a sufficiently complete and representative power quality sample sequence set.

2) Taking into account the influence of the boundary value of each index of power quality, especially taking the boundary value of each index \( m \) times, the corresponding power quality level is the arithmetic average of the two boundary evaluation levels.

3) Construct the following objective function:

\[ \min F(W_j) = \sum_{i=1}^{5n+4m} \left( \sum_{j=1}^{9} y(i)' - y(i) \right)^2 \]

\[ \text{s.t.} \begin{cases} W_j = 1 \\ 0 \leq W_j \leq 1 \end{cases} \]

In the formula: \( W_j \) represents the corresponding power quality index weight, \( y(i) \) represents the corresponding power quality evaluation level, \( y(i)' \) is the evaluation value obtained by various evaluation methods, \( m \) takes the boundary value 20 times, \( n \) Take 100, which means 100 pieces of power quality data that are uniformly distributed.

The above objective function is actually a quadratic programming mathematical model, which can be solved by using the function in matlab software to determine the weight value of each indicator of power quality.
3. Power quality evaluation system and evaluation process

3.1. Power quality evaluation system

The evaluation of power quality is essentially a comprehensive evaluation of the operation level of the power system and the power supply capacity. It is a standard for managing and reminding both power companies and power users to protect the power quality environment of the power system, and it is also the implementation of power quality governance and improvement. The basis for the reference, and the means to verify governance and improve effectiveness. Therefore, formulating a feasible, scientific, comprehensive and reasonable power quality evaluation system is the key to power quality research.

As the scale of the power system grows larger and larger, users have put forward higher requirements for power quality. When evaluating power quality, it is not only necessary to proceed from a system perspective, but also to evaluate power quality based on power quality standards to obtain high-quality power quality. We must also consider the power quality requirements of power users and their electrical equipment. From a development perspective, the initiative of both users and power companies should be used to improve the overall economic and social benefits, rather than emphasizing the partial benefits of a certain aspect.

Different electrical equipment in the power system has different load characteristics. They have different requirements for power supply reliability, and also have different impacts and losses on power quality. This article mainly focuses on the discussion of the power quality evaluation of pollution source users, especially the power quality evaluation for high energy consumption users.

The prerequisite for correct power quality prediction and evaluation for high-energy users is to establish a reasonable, high-quality, and implementable power quality evaluation system. As the State Grid Corporation of China pays more and more attention to the power quality of users, it has provided scientific and detailed regulations for the power quality evaluation of high energy-consuming users. The evaluation method divides the user-based power quality prediction evaluation into a three-level evaluation principle. Considering the different impacts of different users on power quality, different evaluation methods should be adopted for users with different characteristics. According to the requirements of the assessed object on the power quality indicators and the degree of influence, the predictive assessment can be divided into three levels, and the division principle is shown in the figure:

![Diagram](image)

Figure 1. Three-level evaluation principle for power quality prediction
3.2. Power quality evaluation process
First of all, power users need to provide the type, model and electrical parameters of the equipment they use in order to understand the working principle, working characteristics and various parameters of the equipment. In order to judge and determine the power quality evaluation index and evaluation level, and the corresponding power quality evaluation method. The simple flowchart is shown in the figure:

![Flowchart](image)

**Figure 2. Power quality assessment flowchart**

Relevant power laws in China stipulate that during the use of electrical energy, power users are prohibited from disrupting the safety of power supply and use, and are prohibited from interfering with the order of power supply and use. If the power user violates the regulations, the power supply company has full power to contain it. Clear provisions are also given in other rules: the user’s non-linear equipment, impact equipment, fluctuating equipment and three-phase unbalanced equipment will affect and destroy the power quality, or cause disturbances and disturbances to the safe operation of the power system. Damage, then the user must take reasonable and effective measures to eliminate it. If the treatment plan is not taken as required, or the measures taken do not meet the national standards, the power supply company has the right to stop power supply to the user. For the non-linear equipment of a power user that has been put into operation, it needs to be tested at the power supply point of the user equipment. According to the test results, and integrate various power quality indicators, compare with the corresponding national standard values. For those indicators that exceed national standards, effective governance measures must be taken. For users who are applying for electricity, predictive evaluation should be carried out in advance. Only when the evaluation results meet the standards set by the state can they be connected to the grid.

4. Conclusion
This article first discusses the meaning of power quality in depth, and has an in-depth understanding of the concept of power quality. On this basis, power quality indicators such as voltage deviation, voltage sag, three-phase unbalance, voltage fluctuation, voltage flicker, voltage harmonics, frequency deviation, power supply reliability, and power supply service evaluation are given, and each the specific meaning
of the indicators, the impact and harm on power quality, and the relevant national standards and regulations. Finally, the power quality evaluation system is given, and the selection of power quality evaluation methods and the evaluation process are analyzed in detail, hoping to provide reference for power quality management.

References
[1] Zhang Wenhai, Xiao Xianyong, Wang Ying. The application of artificial intelligence algorithms in the field of power quality [J]. Power Supply, 2020, 37(09): 3-8+16.
[2] Zhen Xiaochen. Research on User-Oriented Power Quality Economic Evaluation Method [D]. North China Electric Power University, 2013.
[3] Hu Changjun. Evaluation and governance of power quality for nonlinear loads [D]. Southeast University, 2015.
[4] Qu Mengran, Pang Chengyu, Wang Quan, Yao Junwei, Luo Zilin, Lu Jun, Fu Hao. Comprehensive evaluation of power quality based on game theory and ideal gray relation projection method [J]. Smart Electric Power, 2018, 46(06): 55- 60+87.
[5] Xu Xiaolin. Comprehensive assessment and governance of power quality in AC/DC hybrid distribution network [D]. Yanshan University, 2019.
[6] Su Haoyi. Comprehensive evaluation of power quality under smart grid conditions [D]. Guangxi University, 2012.
[7] Qu Shengnan. Development and application of power information and power quality online monitoring and management system [D]. Northeast Petroleum University, 2014.
[8] Zu Ying. Power quality analysis method based on electricity consumption information collection data [D]. Xi'an University of Technology, 2020.