Research on Distributed Power Quality Monitoring System of Large Centralized Charging Station

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Abstract. The power quality problems of large-scale centralized charging stations are prominent, affecting the operation of the station equipment and the power grid, and a simple and efficient distributed power quality monitoring system is required. Based on the analysis of large-scale centralized charging stations for distributed power quality monitoring system requirements, this paper studies the overall structure of the distributed monitoring system, and analyzes the functional requirements of each part of the monitoring system, and gives the voltage/current power quality Monitoring terminal functions and key device design; by comparing and analyzing the characteristics of various communication technologies, an optimal solution for the communication of the distributed monitoring system in the charging station is given. The proposed system provides a basis for real-time monitoring of multiple monitoring terminals in large-scale centralized charging stations, analysis and timely release of relevant power quality assessment information, and in-depth study of the power quality of various charging piles in the charging station and their mutual influence. At the same time, the formed "point-line-surface" charging station monitoring system can provide a data basis for smart operation and maintenance of charging stations.

1. Introduction

As a new vehicle, electric vehicle is also a distributed power load with energy storage function, which is an important part of energy Internet. The power grid company continues to promote the development of electric vehicles. As large centralized charging stations can better meet the needs of users without changing users' habits, reduce users' investment and waste, and are conducive to maintenance and management, with the advantages of ensuring charging safety, the power grid company has built a large number of centralized charging stations for public transport system, urban rental and urban freight transport.

Large scale centralized charging station is composed of several charging piles. As power electronic equipment, the power quality problems represented by harmonic pollution and three-phase voltage imbalance are prominent, which cause extra electricity expenses of power users, misoperation of computers and other electronic equipment, increase of copper loss and stray loss of voltage transformer line, and increase of power cable line loss. The safe and stable operation of charging station and distribution network may also affect higher voltage level power grid[1]. Therefore, the establishment of an appropriate power quality monitoring system is helpful to timely analyze the power quality level of the charging station, find out the causes of the power quality problems, and give
corresponding treatment measures, so as to improve the power quality, reduce the loss, and ensure the efficient and reliable operation of the charging station [2].

At present, the power grid company will carry out sampling inspection on the charging piles connected to the grid. During the sampling inspection on the arrival of goods in the laboratory, it is found that the output current and current stability accuracy of the charging pile exceed the standard: 1) the error of the output current is more than 1%, and the error of the indication value of the electric quantity is more than 2%, which is more obvious under the condition of low output current; 2) the charging current of some charging piles is different from that of other charging piles. The maximum output current difference is large. At the same time, the power grid company lacks the power quality data of the charging pile in the field operation, so the field test is needed.

The field test is carried out under the condition of multiple charging piles operating at the same time. In large centralized charging station, when multiple charging piles operate at the same time, some charging piles may have problems such as output current, current stability accuracy exceeding the standard, and high harmonic content, which will affect each other. Therefore, when analyzing the power quality problems of large-scale centralized charging station, it is necessary to consider not only the power quality of AC side, but also the operation of each charging pile of large-scale charging station in operation. Therefore, it is necessary to build a distributed power quality monitoring network to realize the full coverage of power quality monitoring of charging station.

According to the demand of large centralized charging station for distributed power quality monitoring system, this paper studies the overall architecture of the system, carries out the specific design of sensor and other key parts, develops the distributed power quality monitoring terminal and monitoring platform, which provides an effective solution for the power quality monitoring of charging pile.

2. Structure of power quality monitoring system for charging pile

2.1 Architecture of current sensor

![Distribution of power quality monitoring system structure of charging station](image)

**Figure 1.** Distributed power quality monitoring system structure of charging station

The power quality monitoring system mainly includes four functions: 1) collecting power quality data effectively, 2) generating power quality data in a unified format through real-time calculation, 3) uploading the data to the upper processing center through the communication network, 4) completing the power quality assessment and other advanced analysis functions in real-time processing.

The traditional power quality monitoring system of electric vehicle charging station mainly monitors the common power quality indexes at the primary side of distribution transformer and AC input side of charging station, mainly including voltage deviation, frequency deviation, three-phase unbalance, total harmonic distortion rate, harmonic content, etc. In order to further study the power...
quality of each charging pile inside the charging station and the interaction between them, it is necessary to build a distributed power quality monitoring network, and form a "point line plane" charging station monitoring system to provide the basis for intelligent operation and maintenance of charging stations. The architecture of distributed power quality monitoring system is shown in Figure 1, which includes three parts: current and voltage power quality monitoring terminal, communication system and remote data platform.

In the monitoring system, each charging pile is equipped with a set of monitoring unit. The monitoring unit completes the function of current and voltage power quality monitoring, and obtains the power quality index values through calculation and analysis; multiple sets of monitoring units in the station upload the data to the collection unit through local wireless communication, and the collection unit will complete the collection and preprocessing of power quality data in the whole charging station, and the data will be stored for a short time, and finally uploaded to the cloud platform. The platform can evaluate the power quality of the charging station comprehensively, quantify the power quality severity, analyze the interaction between charging piles, and have the monitoring index abnormal warning function. It can guide the configuration of power quality problem management methods according to the actual needs, and effectively control the impact of charging station on the power quality of distribution network.

3. Function design of monitoring terminal

3.1. Terminal function requirements

The basic architecture of the voltage/current monitoring terminal is shown in Figure 2. The voltage and current sensors are connected through the main controller to complete the data acquisition, storage and transmission. Among them, in large-scale centralized charging stations, the charging piles are mostly high current piles, which adopt three-phase power supply. Therefore, the voltage can be measured by introducing a measuring voltage line, and the current can be measured by distributed sensors. Its main functions are as follows.

1. Wireless communication: support fast installation, simple and reliable system.
2. It has the functions of acquisition, storage and numerical calculation of steady-state voltage / current waveform: waveform and corresponding RMS, frequency and phase.
3. With harmonic measurement function: harmonic amplitude, phase.
4. It has high frequency transient waveform sampling function such as voltage fluctuation and voltage flicker.

Figure 2. Structure of voltage/current monitoring terminal

3.2. Workflow of monitoring system

After collecting the voltage and current waveforms, the monitoring terminal performs Fourier decomposition to calculate some indexes, and then uploads the data to the collection unit through wireless communication network to calculate all monitoring electrical quantities. The specific workflow is shown in Figure 3.
3.3. Device selection and circuit design

3.3.1 Sensor module selection

The basic indicators of power quality include the RMS value of voltage/current, grid frequency, power, harmonics, etc. The monitoring system needs to accurately measure the steady-state power frequency voltage/current waveform, so the sensor module is the core of the measurement accuracy of the whole monitoring system. The sensor module includes a voltage sensor and a distributed current sensor. The voltage sensor is a coil type sensor, which transmits the analog signal to the monitoring terminal; the current sensor is a distributed design, which measures the current through the magnetic field, and transmits the digital quantity of the current to the monitoring terminal through wired way. In order to ensure that the sensors can be installed on the side of the charging pile, the sensors designed in this system have the characteristics of small size and easy installation [3]. The structure of current sensor terminal is shown in Figure 4.

Analog to digital conversion (A/D module) is an important device to ensure the measurement accuracy. The digital processing module is realized by MCU, which mainly completes the digital signal processing after A/D conversion and the control function of each module of the whole sensing system. In the distributed current sensor, due to the limited precision of the built-in A/D, AD7621 of analog company and STM32 Series MCU of STM32 series of STM32 are used to complete the design of distributed current sensor. The accuracy of current sensor can reach 0.5s level with 16bit sampling accuracy. The distributed current monitoring terminal is shown in Figure 5.

3.3.2 Circuit design

The monitoring terminal will access the analog/digital signals input by current and voltage sensors, and complete the signal preprocessing, storage and communication. In the design, the voltage signal should be modulated first to filter out the noise signal and improve the signal quality. Then the sampling is completed by the external A/D module, as shown in Figure 5.
The main control unit of the monitoring terminal needs to complete the waveform processing and analysis of six voltage / current signals, so the performance of the main control must be strong enough. In the design, STM32f446 is used as the main control chip. The chip’s main frequency is up to 180mHz which can monitor the change of signal in real time and complete the long-time analysis of voltage flicker and fluctuation. The scene of the whole monitoring system after installation is shown in Figure 6.

4. Communication system design

The communication scope of power quality monitoring of charging station is within the station yard, which requires low power consumption, small volume and fast transmission rate. The architecture is shown in Figure 1. Due to the large amount of power quality data, the local communication transmission rate from communication collection unit to station platform needs to be greater than 10kbps.

At present, the commonly used local wireless communication schemes include ZigBee, WiFi, Bluetooth, etc. ZigBee technology is a short distance, low complexity, low power consumption, low rate, low cost two-way wireless communication technology. It is mainly used for data transmission between various electronic devices with short distance, low power consumption and low transmission rate. Due to the power quality needs to transmit waveform data, the speed of ZigBee is slow, so it is not applicable in this system. The disadvantage of 4g-2g is that the data transmission rate is wide, but
the data transmission range is not fast and the data transmission range is slightly poor. In contrast, the low-power consumption and convenient connection characteristics of Bluetooth communication make it suitable for multi node distributed low-speed sensor data upload, and can be used in local communication system of sensor uplink.

5. System function design

5.1. Fast Fourier analysis and design

The common power quality problems of large-scale centralized electric vehicle charging station include power quality transient events such as sag, sag and interruption, and steady-state power quality problems such as voltage deviation, frequency deviation, three-phase unbalance, voltage fluctuation and flicker, harmonic, inter harmonic, three-phase imbalance, temporary or transient overvoltage, etc. Harmonic calculation is the basis of power quality analysis, and the basic method of harmonic calculation is Fourier analysis [4].

In order to ensure the real-time, accuracy and efficiency of the analysis of the above power quality indicators, it is very important to design an efficient fast Fourier transform (FFT) algorithm based on arm in this system. According to the requirements of IEC61000-4-30 standard, the system adopts the base 2 times division FFT algorithm, namely Cooley-Tukey algorithm.

For a finite length discrete periodic sequence \( x(n) \) \( (0 \leq n \leq N-1) \), if \( 1 \leq N \leq \infty \)

\[ \sum_{n=0}^{N-1} |x(n)| < \infty \]  \( \ldots (1) \)

Then the discrete Fourier transform (FFT) can be expressed as follows:

\[ X(k) = \text{DFT}[x(n)] \]

\[ = \sum_{n=0}^{N-1} x(n)e^{-j2\pi nk/N} = \sum_{n=0}^{N-1} x(n)e^{-j\pi n^2k/N} \]  \( \ldots (2) \)

Where \( 0 \leq k \leq N-1 \). \( x_0(i) = x(2i), x_1(i) = x(2i+1), 0 \leq i \leq N/2-1, X_0(k) = \text{DFT}[x_0(i)], X_1(k) = \text{DFT}[x_1(i)] \), then:

\[ X(k) = X_0(k) + W_N^k X_1(k) \]  \( \ldots (3) \)

\[ X(k+N/2) = X_0(k) - W_N^k X_1(k) \]  \( \ldots (4) \)

In this case, \( 0 \leq k \leq N/2-1 \). The algorithm requires that the length of the discrete sequence should be an integer power of 2. If this condition is not met, the method of directly adding zero after the sequence to make its length be an integer power of 2 can be used. The method can quickly realize the decomposition calculation of harmonics [5].

5.2. Application of power quality function

According to the existing national standards of power quality, it can realize the single evaluation of each index and judge the quality of each index. However, power quality is a complex of multiple indicators. It can not reflect the overall situation of power quality by simply judging whether a certain index is qualified, nor is it convenient to quantify the loss caused by disturbance and "pricing according to quality” in the future power market environment. The comprehensive evaluation of power quality based on mathematical statistics method can distinguish qualified power quality and unqualified power quality, and give hierarchical evaluation results, which can provide power quality information for power users from a more intuitive perspective, and provide basis for sensitive power users to select or optimize power quality.

Advanced application of data driven power quality analysis refers to the advanced application of power quality analysis based on the data provided by power quality monitoring system, using data mining technology, artificial intelligence method and signal processing algorithm to complete power quality analysis, such as power quality comprehensive evaluation, voltage sag positioning, power quality disturbance data correlation analysis [6], charging pile state assessment considering mutual
influence. It is estimated that [7, 8], etc. The development and application of advanced application module can further expand the functions of distributed power quality monitoring system and promote the advanced monitoring and intelligent operation and maintenance of large centralized charging station.

6. Conclusions
This paper studies the distributed power quality monitoring system which is suitable for large-scale centralized charging station, and gives the design of each part on the basis of analyzing the demand. The system forms a "point line plane" power quality monitoring system for charging stations, which can be used to study the interaction between charging piles in large-scale centralized charging stations and provide the basis for intelligent operation and maintenance of charging stations. The application of the system helps to improve the level of monitoring and intelligent operation and maintenance of charging station, and improve the operation quality. It should be pointed out that the key to further improve the potential application value of the system is to use distributed power quality test data and further develop advanced applications to meet various needs based on big data, artificial intelligence and other technologies.

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