Development of Distributed Low Voltage Distribution Remote Monitoring System

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Abstract. Intelligent power distribution monitoring technology is an important technology to improve the intelligence and automation level of the power distribution system. However, because the current power distribution monitoring methods in low-voltage power distribution rooms are not very developed, regular manual inspections and manual data recording are needed, leading to efficiency very low, so the research and development of intelligent distribution monitoring system in low-voltage distribution room is very necessary. This system is mainly composed of intelligent electrical parameter collection terminal, 4G data transmission module, Alibaba Cloud Internet of Things platform, and remote power host computer, and each device can perform effective data communication. The system is assigned to each low-voltage power distribution room for unified management and viewing. The low-voltage power distribution real-time monitoring system can realize the real-time monitoring of transformer parameters and wireless transmission, and control the 4G communication module to receive or send data to the Alibaba Cloud Internet of Things platform. The remote cloud can monitor and query electrical parameters in real time, and can also send control instructions to the intelligent collection terminal. The terminal host receives various data (such as the three-phase voltage and current of the transformer, active and reactive power, power factor, frequency, harmonics, environmental temperature and humidity, etc.) from the data collector in real time and analyzes it. Once the data exceeds the set threshold will cause an alarm to prevent potential safety hazards in the low-voltage power distribution room. The experimental results prove that the system can monitor the working status of various electrical equipment in the power distribution room in real time, accurately and efficiently, thereby ensuring the safety and stability of the entire power distribution system, and has certain research value.

1. Introduction

In today's society, with the rapid development and application of modern power electronics technology, the distribution system has also begun to develop in the direction of intelligence and automatic control. The emergence of intelligent power distribution monitoring technology is inseparable from the intelligent development of power systems in various countries around the world. The so-called intelligent power distribution monitoring system is a new type of power distribution monitoring based on the existing power distribution network and power distribution equipment, combining traditional power distribution monitoring technology with modern advanced automatic measurement and control technology, high-speed communication technology and computer technology, System[1].

This topic uses 4G wireless communication technology, with Cortex-M4 chip as the core data processor, and Alibaba Cloud Internet of Things platform as the display medium. Realize real-time and efficient monitoring of three-phase voltage and current, active and reactive power, power factor, frequency, harmonics, and temperature and humidity of the environment. Among them, wireless
communication technology reduces the cost of traditional cable transmission data, improves the reliability of electrical parameter measurement, and M4 chip improves the efficiency of data processing. The use of Alibaba Cloud's Internet of Things platform makes electrical parameter detection more real-time and convenient. This electrical parameter monitoring device is important practical value for ensuring the safe operation of low-voltage distribution cabinet equipment significance.

2. Measurement method and data processing algorithm

2.1. Sampling method and selection
Sampling methods are mainly divided into synchronous sampling and asynchronous sampling. Compared with synchronous sampling, asynchronous sampling has a simple circuit and is easy to implement. It can improve its measurement accuracy. The sampled data has a strong anti-interference ability, but it will cause serious spectrum leakage and fence effect. The generation of may cause each harmonic frequency not to appear in the result of the Fourier transform operation. At the same time, because the spectrum leaks, the spectral line information between the neighbors is lost or covered up, you need to choose a suitable window function and interpolation algorithm to reduce the measurement error in asynchronous sampling[2].

This subject needs to measure electrical parameter signals. When the frequency of electrical parameters is within a certain fluctuation range, when the synchronous sampling method is used, the relationship between the sampling frequency and the signal frequency will change at any time, and it is difficult to achieve true synchronization. Although non-synchronous sampling will cause fence effects and spectral leakage, the sampled data is highly resistant to interference. This system design uses 4 items of 5th order Nuttal windowing interpolation algorithm which will greatly improve data accuracy. Therefore, asynchronous sampling is used.

2.2. Data processing related algorithms

2.2.1. Fast Fourier Transform (FFT). Discrete Fourier transform can transform time domain analysis into frequency domain analysis, and it is easier to obtain the amplitude of each harmonic through frequency domain analysis. But because its operation amount is proportional to N², it is rarely used in actual engineering[2].

On the basis of DFT, the use of FFT (Fast Fourier Transform) algorithm can greatly reduce the amount of calculation. The essence of the FFT algorithm is to continuously decompose the DFT of a long sequence into a DFT of a short sequence, and reduce the amount of DFT operations according to the periodicity and symmetry of the rotation factor[3]. Its periodic expression is as follows:

\[ W_N^{kn} = W_N^{k(N+n)} \]
\[ W_N^{(k+N/2)2n} = -W_N^{kn} \]

2.2.2. Base 4 FFT algorithm. The base 4FFT algorithm divides a sequence of length N = 4^l into four, and represents the N-point DFT as a linear combination of 4 N/4-point DFTs. Then use the symmetry and periodicity of the rotation factor to divide the N/4 point DFT into four, representing the four N/16 point DFT, and repeat it until it is decomposed into a four point DFT operation[3].

2.2.3. Base 4 FFT algorithm complexity analysis. When calculating DFT S(k) of length L with DFT \( S_l(k), l = 0,1,2,3 \) of length L/4, the basic unit implements the following formula:
\[ S(k) = \sum_{l=0}^{3} W_L^l S_l(k) \]
\[ S(k + L/4) = \sum_{l=0}^{3} W_L^{l(k+L/4)} S_l(k) = \sum_{l=0}^{3} W_L^l (-j)^l S_l(k) \]
\[ S(k + 2L/4) = \sum_{l=0}^{3} W_L^{l(k+2L/4)} S_l(k) = \sum_{l=0}^{3} W_L^l (-1)^l S_l(k) \]
\[ S(k + 3L/4) = \sum_{l=0}^{3} W_L^{l(k+3L/4)} S_l(k) = \sum_{l=0}^{3} W_L^l (j)^l S_l(k) \]

Formula (3) is a 4-hour division butterfly calculation formula. It can be concluded that the base 4FFT algorithm requires 3 complex multiplications and 8 complex additions. Since there are N/4 operation butterflies, the number of complex multiplications and additions required for butterfly operations is 3N/4 and 2N, respectively [3].

In the case of \( N = 4^l \) (l is a positive integer), decomposing an N-point sequence into a four-point sequence requires \( l = \log_4 N \) times of decomposition. Therefore, the number of complex multiplications and complex additions required by the base 4FFT algorithm are:

\[ M_c = \frac{3}{4} N \log_4 N = \frac{3}{8} N \log_2 N \]  
\[ A_c = 2N \log_4 N = N \log_2 N \]  

2.2.4. Nuttall window interpolation algorithm. After non-synchronous sampling, the sampled data undergoes FFT processing, which will cause serious spectrum leakage and fence effect. Therefore, the sampled data needs to be processed by window interpolation algorithm before the corresponding electrical parameters are obtained. By comparing the performance parameters of different window functions, it can be found that based on the 4-term 5th order Nuttal window, it can well suppress spectral leakage. The 4-term 5-order Nuttal window function is composed of 4 terms of the cosine function, and its time domain function expression is:

\[ w(n) = \sum_{m=0}^{M-1} (-1)^m b_m \cos(2\pi mn/N) \]  

Where N is the number of sampling points, the n is the serial number and the M is the 4 term cosine function, and m is the serial number of the term. The frequency domain expression of the signal after windowing is:

\[ W(\lambda) = \sum_{m=0}^{M-1} b_m [W_R(\lambda - m) + W_R(\lambda + m)] \]  

The sampled data can suppress the spectrum leakage well after passing through the 4th-order 5th order Nuttal window function, but because the fence effect phenomenon still exists, you need to perform further interpolation processing on the data after FFT operation.

3. Overall scheme design
This system is mainly composed of intelligent electrical parameter collection terminal, 4G data transmission module, Alibaba Cloud Internet of Things platform, and remote power host computer. Effective data communication can be performed between various devices. The low-voltage power distribution real-time monitoring system can realize real-time monitoring and wireless transmission of transformer parameters, control data reception and transmission of 4G communication modules, and send SMS messages. The system structure is shown in Figure 1.
3.1. Hardware framework design

The hardware structure of the electrical parameter acquisition system is shown in Figure 2. The acquisition terminal is mainly composed of STM32 minimum system module, electrical parameter acquisition module, 4G communication module, liquid crystal display module, temperature and humidity sensor module, etc. The electrical parameter monitoring module adopts voltage and current mutual inductance isolated sampling mode. The STM32 collects the electricity consumption data measured by the electricity metering module through the RS485 communication circuit, and converts the electrical parameters to be detected.

3.2. Software framework design

The software of the intelligent low-voltage distribution room intelligent power distribution monitoring system adopts a modular design concept and an object-oriented design idea, and divides the software into several sub-modules. It mainly includes system initialization module, electrical parameter acquisition calculation module, temperature and humidity acquisition module, liquid crystal display module and 4G communication module. The functional programs of each sub-module are written from the underlying driver functions, and adopt the upward inheritance method to achieve the functional requirements of the corresponding modules. Input and output data between the modules through various interfaces, which is conducive to the expansion and deletion of functions. The main flow block diagram is shown in Figure 3.
4. Wireless communication mode
The design of this project uses 4G modules for wireless communication. Although 4G modules have large power consumption, compared with various communication methods on the market at this stage, 4G communication rates are the highest, especially with the arrival of the 5G commercial era. The way information is exchanged will change. In the 4G Internet of Things, the intelligent electrical parameter collection terminal is connected to the base station through the EC20 module. The 4G base station completes the communication between the Alibaba Cloud operator network and the 4G network device. The cloud server implements data transmission and forwarding, and sends the data directly to Alibaba Cloud. With the Internet of Things platform, users can log in to their Ayun Internet of Things account to query the received electricity-related data and manage the data.

The data transmission module EC20 of the intelligent electrical parameter acquisition terminal supports multiple transmission protocols such as MQTT, HTTP, TCP. When the MQTT transmission protocol is used, it has the advantages of simple networking and convenient development. It transmits data to Alibaba Cloud IOT platform and IOT platform. It can achieve data cache, management and analysis. The cloud server can access the IOT platform through the data query interface, or push data to the cloud server[4]. The network architecture of 4G IoT technology is shown in Figure 4.

Figure 4 4G module and Alibaba Cloud communication network architecture diagram
5. System function and innovation

5.1 Main functions of the system
Through the research of this topic, based on the hardware design, complete the software design based on the distributed low-voltage power distribution remote monitoring system and the management of the cloud monitoring platform, and conduct the overall performance test. The main functions implemented are as follows:

(1) Data acquisition function. The collected data includes three-phase voltage and current, active power, reactive power, power factor, frequency, harmonic components and other data for statistical analysis of electrical quality. Users can monitor the current status of the on-site power distribution room in real time, and alert the outlier system in an eye-catching manner. The system saves the collected data to a historical database, providing analysis and query of historical data.

(2) Environmental quality monitoring. It can monitor the environmental parameters of the low-voltage power distribution room, such as temperature and humidity parameters, and monitor the environmental conditions of the power distribution room in real time to prevent a series of dangerous events that may be caused by the heating of the power distribution cabinet caused by excessive power consumption.

(3) Data analysis and event recording. The recorded data is transmitted to the Alibaba Cloud IoT platform in the form of 4G wireless communication. The form includes data collection operation events, communication status events, and device parameter changes. There is a large storage space to ensure long-term normal recording functions. The cloud platform provides a self-explanatory interface that displays the current status of all channels, making it easy for users to find out the status of low-voltage power distribution rooms with communication faults.

5.2 Innovation point analysis
This topic monitors the data of multiple distributed collection points at the same time, and organically combines distributed monitoring technology, wireless communication technology, and cloud platform sharing technology to achieve remote monitoring of electrical parameters of distributed low-voltage distribution, which is convenient for users at any time View anywhere. There is no need to design corresponding communication forwarding equipment, and data can be transmitted to the cloud directly through the 4G communication module.

This project can not only measure electrical parameters, but also analyze and calculate power quality, monitor the environmental parameters of the power distribution room, and upload the records to the Alibaba Cloud Internet of Things platform. Users can view the power consumption of various parameters in any past time Change the situation so as to avoid the risk of electricity consumption and understand the basic situation of the power distribution room.

6. Conclusion
This subject designs and implements the development of a distributed low-voltage power distribution remote monitoring system, which can measure various electrical parameters in real time and has the function of environmental parameter analysis. Compared with traditional measurement technology, using the Internet of Things to view the cloud is very safe and convenient, and it also improves the inspection efficiency. The STM32F407 single-chip microcomputer is used as the main control core, and the 4G data is transmitted to the cloud to interact with the user. The electrical parameters are displayed intuitively, which is convenient for users to check and avoid the risk of power consumption. The basic 4FFT algorithm and Nuttall window interpolation algorithm applied in this paper are the key to achieving this design requirement. It can perform harmonic analysis on the current and voltage signals, and make its electrical parameters, environmental parameters and other data clear and dynamic on the Alibaba Cloud IoT platform The display shows that it overcomes the characteristics of incomplete display of electrical parameters of the detection output, low accuracy, and poor stability.
Finally, the standard PCIe interface used in the hardware of this project is compatible with the use of 5G modules, so this project will also provide valuable experience for the research of 5G smart grids.

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