Research on Real-time Data Acquisition Technology Based on Distribution Automation Technology

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Abstract. The remote terminal equipment data collection system of distribution automation plays a decisive role in the monitoring of distribution networks. The thesis studies the key technologies of distribution network operation and real-time data collection of topology data, analyses various new technologies of ICT, designs the basic technical architecture of real-time data collection, and realizes the automatic connection of various professional data of distribution networks such as equipment, marketing, and scheduling. Into a unified distribution network database that integrates various disciplines, multiple themes, and multiple applications, comprehensively improves the quality of distribution network data, and provides a basis for distribution network diagnosis and big data analysis. At the same time, the paper performs software filtering on the data and uses fast Fourier transform to improve real-time performance. Using a signal generator and a high-precision switching power supply as the signal input, the frequency test, voltage accuracy test and fast Fourier transform experiment were conducted respectively. The experimental results show that the simplified terminal data collection system has higher accuracy and stability.

Keywords: Distribution automation technology, real-time data acquisition, remote end of distribution automation, fast Fourier transform.

1. Introduction

At present, with the development of social economy, the number of power grid users and the frequent changes of the power grid, the probability of distribution network failure increases, the operation of dispatch and operation is more complicated, and the workload of operation and maintenance is increased. It is also proposed in terms of safety and reliability further challenges, relying heavily on manual monitoring and management of the operating state of the power grid, with low efficiency and poor results. Therefore, through the massive operation data generated by the operation of the distribution network, the specific conditions of the power grid operation are monitored in real time, and the power transmission is regulated in real time to ensure the user's power quality, effectively prevent the theft of metering devices, and improve the economic operation level of the power grid. Solve real problems.

Nowadays, smart meters are widely used, and the power data collection technology is relatively mature. However, due to the curve information, power outage events, and phase data of power distribution network equipment, power outage events, and phase data have not been widely or
standardized, and are limited by the existence of narrow-band carrier technology. The limitations of low communication rate, susceptibility to interference, slow networking progress, and insufficient business support capabilities, incomplete data collection and low data quality in the distribution network are common problems that severely restrict the information management of the distribution network. Compared with the narrow-band carrier, the high-speed carrier technology can directly use the power line without rewiring. The networking is relatively simple and fast, the cost is low, and the anti-interference is strong. The acquisition bandwidth and rate are greatly improved, and the transmission reliability it is guaranteed to provide the necessary conditions for automatic identification of distribution network topology, accurate fault diagnosis and intelligent auxiliary planning. With the vigorous promotion of the "Digital State Grid", the popularization and application of new ICT technologies, especially the deepening application of distribution automation technology, and the rapid development of high-speed carrier technology, can continuously improve the data collection quality and automation level of distribution networks. Integrate information such as operation inspection, marketing, scheduling, etc., build a multi-topic, multi-application data platform, build an online quantitative assessment mechanism based on automatically generated indicators, improve grassroots work efficiency and lean management level, for distribution network data fusion sharing, information deep mining And the improvement of data quality provides new ideas [1].

2. System requirements analysis

2.1. Requirements for monitoring of distribution network operation equipment

The distribution network has the characteristics of long lines, wide distribution area, complex network structure, diverse equipment types, wide operating points, and relatively poor security environment. According to its tree-like network structure, in accordance with the "station-line-change-household" hierarchical relationship, it is monitored step by step to ensure safe and reliable operation of the distribution network [2].

2.2. Distribution network operation data collection requirements

(1) Voltage: Also called potential difference or potential difference, it is a physical quantity that measures the energy difference of unit charge in electrostatic field due to different potentials. The main unit in the International System of Units is volts, abbreviated volts, which is represented by the symbol V.

(2) Current: The amount of electricity passing through any cross section of a conductor in a unit of time is scientifically called current intensity, abbreviated as current, the current symbol is I, and the unit is ampere (A), abbreviated as "ampere".

(3) Active power: Active power refers to the AC energy actually emitted or consumed per unit time, which is the average power in the cycle. In a single-phase circuit, it is equal to the product of voltage effective value, current effective value, and power factor. In a multi-phase circuit, the number of phases is multiplied by the active power of each phase. The unit is watt and kilowatt.

(4) Reactive power: Reactive power means that in an AC circuit with reactance, the electric field or magnetic field absorbs energy from the power source during a part of a cycle, and releases energy at another part of the time. The average power is zero throughout the cycle, but energy is constantly exchanged between the power supply and the reactive elements (capacitors, inductors). The maximum value of the exchange rate is "reactive power".

2.3. Distribution network operation and maintenance business monitoring requirements

Based on the characteristics of the distribution network, the operation data of the distribution network is reasonably used to construct operation monitoring and alarm event display scenarios according to business needs, and three-dimensionally present relevant information such as power supply path, operation information, switch status, temperature monitoring, influence range, and loss load. As shown in Table 1.
Table 1. Monitoring requirements of main equipment in distribution network

| Serial number | Monitoring equipment | Data collection | Business involved | Acquisition frequency |
|---------------|----------------------|----------------|-------------------|-----------------------|
| 1             | Substation           | Voltage, current, active power, reactive power, power factor, power, phase sequence | Distribution network planning, line loss management, fault repair, technical renovation and overhaul, power outage and recovery events, distribution automation, load transfer, rural power grid transformation, 400V distribution network, power supply range selection | 24h real time |
| 2             | Distribution line    |                |                   | real time |
| 3             | Distribution transformer |                |                   | real time |
| 4             | User meter           | Voltage, current, active power, reactive power, power factor, power, phase sequence |                  | real time |

3. Overall system design

3.1. Real-time collection technology architecture of distribution network operation data

Figure 1 is a hardware block diagram of a new type of data distribution automation terminal data acquisition system. The hardware circuit of the new distribution automation terminal adopts a modular design idea and is divided into 5 modules according to function: AC input module, measurement and control module, protection module, communication module and display module. Each module cooperates with each other to realize the data collection function. The data collected by the DTU terminal includes: three-phase voltage, current, active power, reactive power, the status of the switching equipment and other information.

![Figure 1. Block diagram of the data collection system of the distribution automation terminal](image-url)
The AD7606 high-precision sampling chip is used in the measurement and control module. The frequency measurement circuit adjusts the sampling frequency in real time. The data extraction algorithm uses FFT fast Fourier transform. As an auxiliary module, the communication system transplants theμC/OS-II embedded real-time operating system into the Cortex-M3 core of STM32, and transplants the Lw IP protocol stack under the operating system to realize TCP/IP protocol communication. Compatibility and stability [3].

3.1.1. Medium pressure section. Install line-transformation relationship recognition equipment based on medium-voltage carriers on 10kV lines. Install the identification device host at the exit of each 10kV line, and install the identification device slave on each public and special transformer on the line, as shown in Figure 2 below:

![Figure 2. Medium voltage carrier structure on 10kV line](image)

The medium voltage carrier communication master forms a local area network with all medium voltage carrier communication slaves on the current line. The communication host can use the registration method of activating the slave node to obtain the slaves that really exist on the current line, and communicate in real time, read the total number of the transformer in the slave device, and the master can keep the information synchronized with the master in real time. The medium-voltage carrier communication link is established by installing a coupler on the 10kV line, and the host and the slave establish a medium-voltage carrier network based on the link to perform data transmission. The medium voltage carrier signal turns the strong electricity into the weak signal through the coupler, and uses the carrier chip to modulate and demodulate the signal. It not only completes the isolation of strong and weak electricity, but also realizes the signal transmission. Since each slave can be used as a relay, it can ensure reliable communication of the medium voltage carrier of the entire 10kV line.

3.1.2. Low voltage part. Install a concentrator with operation data monitoring function in the low-voltage station area. The concentrator is connected to the total table of the station area through the RS-485 interface to collect the total table data; the concentrator collects the data of each meter, branch box terminal and meter box terminal through the high-speed carrier module. As shown in Figure 3.
Figure 3. Low-voltage station area installation with data monitoring function

A branch box monitoring terminal is installed at each outlet switch of the branch box. The terminal has built-in station identification chip, high-speed carrier chip and metering chip, which can monitor the operating information of the voltage, current, power and power factor of each branch switch, monitor the switch status and real-time report the opening and closing event. Install a meter box monitoring terminal in the meter box. The terminal has built-in station identification chips, high-speed carrier chips and metering chips. It can monitor the operating information of the voltage, current, power and power factor of each meter box, monitor the switch status of the meter box and report it in real-time. Opening and closing event; collect the information of each meter in the meter box via RS485 line to monitor the electricity consumption of the meter. The smart meters on the low-voltage station area all replace high-speed carrier modules for data transmission [4].

3.2. Communication protocol
The communication interface is a necessary channel for data exchange between modules or levels. In the communication module, there are 2 independent serial interfaces RS-232, 2 RS-232 and RS-485 shared interfaces and 1 TCP/IP communication interface. The TCP/IP protocol of the communication module is implemented on the μC/OS-II operating system. The operating system has good portability and tailorability, and has the characteristics of multitasking and deprivation. This communication module has the following 2 steps to realize the TCP/IP communication protocol:

1) Transplant the μC/OS-II operating system on the STM32 controller. Transplanting μC/OS-II embedded operating system on STM32 requires macro definition modification of the three files OS_CPU.H, OS_CPU_C.C and OS_CPU_A.ASM. 2) The Lw IP protocol stack needs to be ported on the μC/OS-II operating system. The mailbox and message queue using μC/OS-II communicate with the TCP/IP process, and the communication with the protocol stack uses a call back function (Raw API).

4. Terminal data collection and analysis technology

4.1. Comparative analysis of data collection technology

4.1.1. Micropower wireless technology. Micropower wireless communication technology is to transmit and receive information through micropower radio communication module (transmitting power is less than 50mw). It has the advantages of no wiring, strong real-time, and meter reading across stations. It adopts wireless ad hoc network communication technology, simple installation, flexible networking and easy maintenance.

Micropower wireless communication technology refers to wireless radio frequency communication using 433 MHz/470 MHz/780 MHz/2.4 GHz frequency and transmitting power less than or equal to 50 mW. Use micro-power wireless technology to acquire the distribution network data, first collect the
client energy meter data through the collector, and then transmit the data to the concentrator through the micro-power wireless channel, and the concentrator uploads the data to the actual business system.

4.1.2. Narrow-band carrier and high-speed carrier technologies. Narrow-band carrier and high-speed carrier technologies belong to the category of power line carrier communication (PLC) technology. The difference lies in the transmission signal frequency. Narrow-band carrier communication generally uses 10kHz~500KHz signals for transmission, while the signal frequency range of high-speed carrier communication is in 2MHz~20MHz. The difference in the actual application effect of wideband/narrowband carrier communication should first be analysed from the three aspects of communication rate, noise interference and transmission reliability according to technical principles.

In terms of communication rate, Shannon's theorem states that under Gaussian white noise interference, the limit transmission rate (or channel capacity) of a communication system is:

\[ C = B \log_2 \left(1 + \frac{S}{N}\right) \]  

(1)

To increase the information transmission rate of the system, it is required to increase the channel capacity. The method of increasing the channel capacity can be achieved by increasing the transmission signal bandwidth B, or increasing the signal-to-noise ratio S/N. Among them, B is proportional to C, and C and S/N are in a logarithmic relationship. Therefore, increasing B is more effective than increasing S/N. In other words, the high-speed carrier can effectively increase the channel capacity.

However, when B increases to a certain degree, the channel capacity C cannot increase infinitely. The channel capacity C is proportional to the signal bandwidth B. Increasing B will inevitably increase C, but when B increases to a certain degree, C increases slowly. This is because as B increases, the noise power \(B n N\) must also increase, so that the signal-to-noise ratio S/N decreases, which ultimately affects the increase in C.

\[ \lim_{B \to \infty} C = \lim_{B \to \infty} B \log_2 \left(1 + \frac{S}{N}\right) = \lim_{B \to \infty} B \log_2 \left(1 + \frac{S}{n_s B}\right) \]

(2)

It can be seen that when the signal power S and the noise power spectral density \(n_s\) are fixed, the channel capacity C is limited, that is, the limit transmission rate \(R_{max}\) is limited.

4.2. Design of low-pass filter of measurement and control module

Figure 4 is a block diagram of the data acquisition process of the measurement and control module. When sampling voltage and current signals, the transformer conversion circuit and the conditioning circuit are first used to step down the signal, and then the signal is collected through the low-pass filter and the op-amp follower circuit. And the Fourier transform, amplitude frequency analysis, phase frequency analysis and effective value calculation of the sampled digital signal [5].
4.3. Power line channel data transmission model

To achieve high-quality communication on the power line, it is necessary to fully understand the characteristics of the power line channel and establish a corresponding mathematical model. Mathematical models commonly used for various types of noise in power line channels include the following:

4.3.1. Background noise. Since the background noise is a typical discrete Gaussian type noise, according to Wold's theorem, it can be simplified to an autoregressive (AR) model, and the white noise with the variance is subjected to specific shaping and filtering to obtain the background noise. The transfer function \( H_{\text{mod}}(z) \) of noise shaping and filtering in the z-plane is:

\[
H_{\text{mod}}(z) = \frac{B(z)}{A(z)} = \frac{1 + \sum_{i=0}^{m} b_i z^{-i}}{1 + \sum_{i=0}^{n} a_i z^{-i}}
\]  

(3)

In the above formula, \( B(z) \) represents the moving average part, \( A(z) \) represents the autoregressive part, and the values of the parameters \( a_i \) and \( b_i \) can be obtained by measuring the noise signal with a spectrum analyser.

4.3.2. Narrowband noise. Narrowband noise has the characteristics of long duration and large energy after it is generated. If a single frequency carrier is used and the carrier frequency is located near the noise frequency, the communication quality of the system will be greatly reduced. The narrow-band noise in the power line can be generated using the superposition of \( N \) mutually independent sinusoidal functions, as in:

\[
N_{\text{narrow}}(t) = 1 + \sum_{i=1}^{N} A_i(t) \sin(2\pi f_i t + \phi_i)
\]  

(4)

Among them, \( A_i(t) \), \( f_i \) and \( \phi_i \) represent the amplitude, frequency and phase of each sine function. The amplitude can be either a constant or the amplitude of the AM signal; the phase interval is randomly selected on \([0, 2\pi]\).

4.3.3. Impulse noise. The Middleton Class A noise model is one of the commonly used mathematical models for expressing the impulse noise characteristics of power lines. It consists of many impulsive noises that obey Poisson distribution. The probability density function of the noise amplitude of the Middleton Class A noise model is:
\[ P(v) = \sum_{k=0}^{\infty} \frac{e^{-A} A^k}{k!} \frac{1}{\sqrt{2\pi\sigma_k}} \exp\left(-\frac{v^2}{2\sigma_k^2}\right) \] (5)

In the formula, A represents the pulse index, \( \sigma = \sigma_g^2 / \sigma_{\tau}^2 \), \( \sigma_{\tau}^2 = \sigma_g^2 + \sigma_{\tau}^2 \).

4.3.4. Multipath transmission model. In order to represent the signal attenuation characteristics and frequency selection characteristics in power line channels, Zimmermann proposed a multipath power line channel transmission model, the mathematical expression of which is:

\[ H(f) = \sum_{i=1}^{N} g_i(f) e^{j\phi_i(f)} e^{-j\pi f \tau_i} e^{-(a_i + a_{\tau} f^2)d_i} \] (6)

Where \( \sum_{i=1}^{N} g_i(f) e^{j\phi_i(f)} \) is the weighting factor, \( e^{-j\pi f \tau_i} \) is the delay part, \( e^{-(a_i + a_{\tau} f^2)d_i} \) is the fading part, \( i \) is the number of paths, \( N \) is the total number of receiver paths that the signal can reach, \( g_i \) is the weighting factor of path \( i \), and \( \tau_i \) is the delay of path \( i \), \( k \) is the attenuation factor index, \( a_i, a_{\tau} \) is the attenuation parameter, and \( d_i \) is the length of path \( i \).

5. Experimental testing

In order to verify the sampling accuracy of the system, a large number of samples of different voltage input values are collected and compared with the error of traditional measuring devices. The sampling test data and sampling error analysis of this design are shown in Table 2 and Table 3.

| Table 2. Voltage sampling values |
|---------------------------------|
| input signal \(/V\) | Test Data 1/V | Test Data 2/V | Test Data 3/V |
|---------------------|----------------|----------------|----------------|
| 3.001               | 3.002 3        | 2.993 7        | 2.995 2        |
| 3.498               | 3.490 4        | 3.488 2        | 3.491 7        |
| 4.001               | 3.994 2        | 3.993 0        | 3.992 8        |
| 4.499               | 4.494 0        | 4.493 1        | 4.492 1        |
| 5.005               | 5.001 8        | 5.002 8        | 5.001 1        |
| 5.502               | 5.501 4        | 5.499 6        | 5.498 5        |
| 5.999               | 5.997 6        | 5.994 9        | 5.995 2        |
| 6.497               | 6.498 8        | 6.498 1        | 6.498 7        |
| 7.001               | 6.997 4        | 7.000 0        |                |

| Table 3. Error analysis of voltage sampling value |
|---------------------------------|
| input signal \(/V\) | test 1 error \(/\%\) | test 2 error \(/\%\) | test 3 error \(/\%\) |
|---------------------|----------------------|----------------------|----------------------|
| 3.001               | 0.044 9              | -0.241 9             | -0.193 9             |
| 3.498               | -0.217 3             | -0.279 4             | -0.179 1             |
| 4.001               | -0.170 7             | -0.199 2             | -0.205 7             |
| 4.499               | -0.111 6             | -0.130 7             | -0.153 2             |
| 5.005               | -0.063 4             | -0.043 7             | -0.077 5             |
| 5.502               | -0.010 2             | -0.043 3             | -0.063 4             |
| 5.999               | -0.023 7             | -0.067 9             | -0.063 4             |
| 6.497               | 0.028 4              | 0.016 7              | 0.026 5              |
| 7.001               | -0.016 5             | -0.051 3             | -0.013 8             |
It can be seen from Table 2 that the accuracy of the measured voltage values is in the mV level, which is very close to the input signal. From the error analysis in Table 3, it can be seen that the error between the low voltage of 3.5 V and 4.5 V is slightly larger than that of other groups of data. The main reasons for the error are: 1) AC interference in the test environment; 2) Test data fitting curve there is a certain deviation at low voltage. In practice, sampling multiple sets of data and taking the average can achieve the best results [6].

6. Conclusion
In order to optimize the collection efficiency and quality of distribution network operation data, this paper first compares different data collection and transmission technologies and determines the advantages of high-speed carrier technology. After studying the characteristics of the power line channel, and designing the data collection technology architecture, selecting the communication protocol used and analysing its message structure, and finally deepening the application research of the power carrier technology, closely following the needs of the distribution network, in order to achieve "full collection success, complete data The goals of "six totals", such as automatic, full synchronization of files, full penetration of relationships, full compliance with indicators, and full monitoring of abnormalities, laid the foundation.

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References
[1] Cai, C. Yao, E., Zhang, Y., & Liu, S. Forecasting of passenger flow's distribution among urban rail transit stations based on afc data. Zhongguo Tiedao Kexue/China Railway ence, 36 (1) (2015) 126-132.
[2] Shi, J. Zhou, F., Zhu, W., & Xu, R. Estimation method of passenger route choice proportion in urban rail transit based on afc data. Dongnan Daxue Xuebao, 45 (1) (2015) 184-188.
[3] Abeykoon, A. M. M. Hu, H., Wu, L., Zhu, Y., & Billinge, S. J. L. Calibration and data collection protocols for reliable lattice parameter values in electron pair distribution function studies. Journal of Applied Crystallography, 48 (1) (2015) 244-251.
[4] Bowler, M. W. Mueller, U., Weiss, M. S., Sanchez-Weatherby, J., Sorensen, L. M., & Thunnissen, M. M. G. M., et al. Automation and experience of controlled crystal dehydration: results from the european synchrotron hcl collaboration. Crystal Growth & Design, 15 (3) (2015) 1043-1054.
[5] Chen, L. W. Peng, Y. H., Tseng, Y. C., & Tsai, M. F. Cooperative sensing data collection and distribution with packet collision avoidance in mobile long-thin networks. Sensors, 18 (10) (2018) 15-19.
[6] He, Q. Wang, H., Zhuang, F., Shang, T., & Shi, Z. Parallel sampling from big data with uncertainty distribution. Fuzzy sets and systems, 258 (1) (2015) 117-133.