Design of Intelligent Fusion Terminal System with Fog Computing Capability in Distribution Area based on Large Capacity CPU

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***Abstract*—The intelligent fusion terminal in the distribution area usually adopts the mode of cooperation between the cloud and the edge, and the workload of manual operation and maintenance is large. Therefore, an intelligent fusion terminal system in the distribution area with fog computing capability based on a high-capacity CPU is proposed. Follow the "cloud pipe edge end" construction framework of smart IOT system, and take this framework as the edge computing node of distribution station area and power consumption side. Mt7622b chip in Linux operating system with openwrt firmware is used as the main control chip of edge agent gateway equipment, and the recursive least square method is used to realize the data fusion of power acquisition service in distribution station area and power distribution demand terminal. The test results show that the designed system can realize real-time monitoring of power consumption and distribution data and power quality management in the distribution station area, and the data processing delay is less than 100ms, which provides a reference for the intelligent fusion terminal system in the distribution station area.**

Keywords—Large-capacity CPU; fog computing capability; power distribution station area; intelligent integration; terminal; system design

I. Introduction

The communication demands of power users and the intelligent terminal equipment of the power grid are growing linearly. The communication network of many terminal devices in the distribution network station area needs to have a high level of manual operation and maintenance, which puts forward higher requirements for delay, bandwidth and communication flexibility [1]. The intelligent terminal in the station area is the core unit of measurement and control management in the current intelligent power distribution system. The intelligent terminal in the station area is usually installed on the side of the distribution transformer. It uses the intelligent terminal in the station area to realize the communication interaction of the main station system and the access of the lower-level intelligent equipment [2-3]. The intelligent terminal equipment in the station area is of high importance and has a huge impact on the power distribution system. The distribution station area is the junction of production and marketing. Both the production and marketing parties install distribution transformer terminals and concentrators on the station side based on business needs. There are problems such as non-sharing of data, duplication of functions, and increased operation and maintenance workload [4-5]. The intelligent fusion terminal device can realize the functions of the concentrator and the distribution terminal, reducing the cost of equipment procurement, reducing the workload of manual operation and maintenance, and saving the cost of operation and maintenance.

At present, there is much researches on terminal data analysis of power distribution systems. Literature [6] designs a remote terminal data acquisition system for intelligent power distribution automation. The author in [7] proposes an automatically test system for intelligent substation relay protection equipment based on information fusion, which can separately collect data from remote terminals of intelligent power distribution and automatic test of intelligent substation relay protection equipment. Although the above research has achieved certain results and has certain application performance, it does not have the function of improving the data processing efficiency of the intelligent fusion terminal in the distribution station area. To this end, a large-capacity CPU-based intelligent fusion terminal system with fog computing capability is proposed in the distribution station area. Fog computing is based on the concept of cloud computing. In the fog computing mode, the data processing of many intelligent terminals is concentrated on the network edge devices, which effectively improves the data processing efficiency [8]. Applying fog computing to data management in distribution station area can effectively reduce data transmission delay and improve data communication capabilities. The innovation of the research is to use fog computing and large-capacity CPU to improve the data processing capability and communication performance of the system, as an intelligent terminal management device with many functions such as power quality monitoring, distribution transformer detection, humidity and temperature monitoring, etc. It has a high degree of integration, many functions, realizes remote control of intelligent terminals, and has high applicability.

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II. Intelligent Fusion Terminal System in Distribution Station Area with Large-capacity CPU with Fog Computing Capability

A. System Overall Structure

The designed intelligent fusion terminal system in the distribution station area has the functions of a concentrator and TTU, and can be used as the edge computing node in the distribution station area and the power consumption side. The distribution station area takes the intelligent fusion terminal system of the distribution station area as the core, and establishes an intelligent low-voltage distribution Internet of Things with distribution automation. The overall structure of the intelligent fusion terminal system in the power distribution station area with a large-capacity CPU designed with fog computing capability is shown in Fig. 1.

As can be seen from Fig. 1, the designed system follows the "cloud-pipe-side-end" construction framework of the smart IoT system, which can realize the intelligent integration of the power distribution station area's use and procurement services and power distribution requirements. The system supports the communication protocols of the mining system, power distribution and unified IoT management center. Using container technology, multiple containers can be run at the same time, data communication between containers is supported, and data exchange and sharing functions between containers. The marketing application in the distribution station area and the distribution application are installed in their respective containers, and all the functions of the system are realized by using the application APP they have.

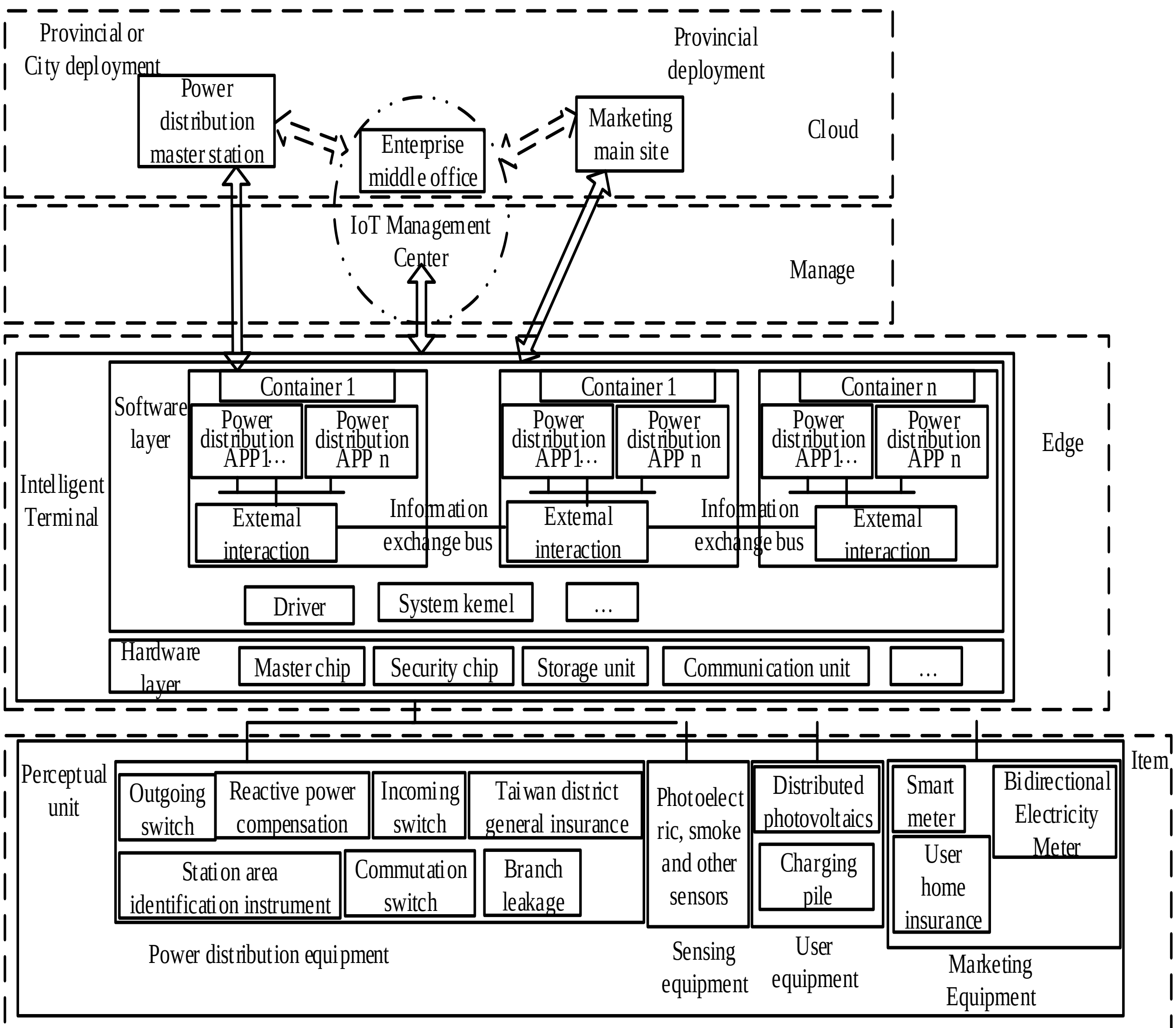

Fig. 1. System Overall Structure Diagram.

The system has external module communication data transmission application, container construction, data recording log and abnormal work log, running status monitoring, remote software and hardware information query, data recording and data statistics, event recording and reporting, parameter setting and query functions. The intelligent fusion terminal system has edge computing capabilities, and integrates the functions of power supply and consumption information collection in the distribution station area, energy meter or collection terminal data collection, equipment status monitoring and communication networking, local analysis and decision-making, and collaborative computing. The hardware adopts a platform-based design, supports the edge computing framework, and has fog computing capabilities [9], which can realize flexible expansion of functions through software-defined methods.

1) System hardware design: The hardware of the intelligent fusion terminal includes the basic core board, the main control board, the carrier module, the acquisition board, the power supply module, the single 4G module, and the dual 4G module. The hardware performance indicators of the fusion terminal are better than the reference standard requirements, and have good consistency. The hardware is designed based on the main control chip. The chip adopts the MT7622B architecture single-core 4-core processor, the main frequency is 1.35GHz, and the peripheral integrates 2GB DDR3 SDRAM and 8GM FLASH memory, two-way Gigabit Ethernet and other peripheral interfaces [10]. The software is based on an autonomous controllable operating system, Docker containers and autonomous orchestration technology.

The main control chip of the edge proxy gateway device adopts MT7622B, the peripheral is equipped with STM32 main control, and the MT7622B chip runs the OpenWRT operating system. It mainly realizes IO expansion and related acquisition functions. The software uses Ubuntu 16.04 operating system to compile openwrt firmware. Flash the compiled firmware into flash, and then run docker in the system to manage the entire application in a containerized manner. STM32 is developed with STM32 library to realize driver layer and application layer encapsulation.

The MT7622B chip adopts the Linux operating system of OpenWrt firmware. In order to ensure the normal and stable operation of the application, the firmware is cut and transplanted, and burned to the hardware platform. According to functional requirements, they increase or decrease related peripheral interface drivers, so that the overall system framework can meet the work requirements and be more streamlined. The main control chip has limited pins [11], and the terminal platform is equipped with an MCU chip as a data transfer hub. The MCU chip is used to connect the relevant peripheral modules, and communicate with the MT7622B main control chip through the communication interface, so that the main control chip can control the relevant peripheral modules.

MT7622B integrates dual ARM®Cortex-A53 cores, with a working frequency of up to 1.35GHz, with strong computing power and working stability. The high-speed DDR3 interface can be connected to high-capacity DRAM chips. It supports a variety of NAND Flash interfaces to realize mass storage control. The chip also includes various peripherals, including UART, SGMII, RGMII, PCIe2.0, USB2.0 (Host), USB3.0 (Host), and a 5-port 10/100 switch. It supports hardware router function, realizes 2.5Gbps HSGMII and 1Gbps RGMII Ethernet interface, embedded 5-port 10/100 switch and 802.11n 2.4GHz wireless. It can be supported by 802.11ac WLAN connection, and a variety of external network connection methods are available.

2) System software design: The system software platform provides a stable operating environment for the fusion terminal. The software platform is used to realize the decoupling of system software and hardware and software APP. The software platform includes the operating system and the edge computing framework.

The operating system completes the design of the root of trust and the chain of trust based on Linux. We have completed the driver design of all peripheral interfaces of the terminal, completed the kernel tailoring optimization and patch upgrade [12], and realized the kernel's support for the self-developed container management and terminal management platform.

The edge computing framework includes the container management engine Docker, system management, and various layers of components for edge-side application development, supporting various business applications. It has realized Docker's management of system-level single container and multiple APPs. It implements various functions such as container start, stop, uninstall, and deletion, APP start, stop, uninstall and deletion, and APP and container quota management.

B. Edge Proxy Gateway Device with Fog Computing Function

1) Edge proxy gateway device: Fog computing data processing and applications are concentrated in network edge devices rather than being stored in the cloud. The distribution station area is the intersection of production and marketing. Based on business needs, both production and marketing parties install distribution transformer terminals and concentrators on the side of the station area. There are problems such as non-sharing of data, duplication of functions, and increased operation and maintenance workload [13]. To solve such problems, the edge proxy gateway device with fog computing function is applied to the intelligent fusion terminal system in the distribution station area. The structure diagram of the edge proxy gateway device with fog computing function is shown in Fig. 2.

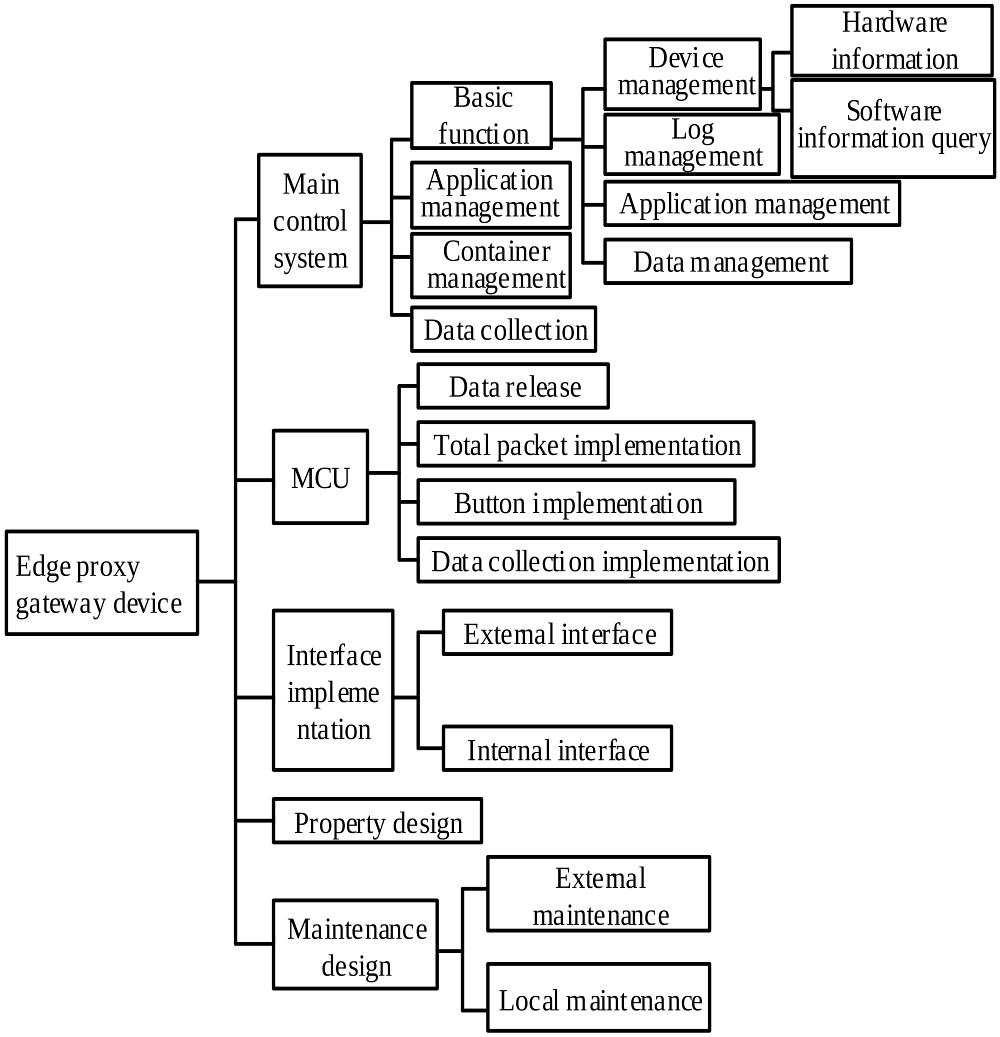

Fig. 2. Edge Proxy Gateway Device Structure Diagram.

The edge proxy gateway device includes a gateway system and a shell, and the gateway system includes a main control system, a single-chip microcomputer, an interface implementation, an attribute design and a system maintenance design. There is installation and positioning holes at the ends of the casing, and the installation and positioning holes are in a symmetrical state with respect to the central axis of the casing. A gas inlet window, a sequence area, a power button and a setting button are arranged on one side of the casing. The sequence area is located at the top of the gas inlet window, and the setting button is located between the sequence area and the power button. The edge proxy gateway device can monitor the devices in the distribution station area [14]. It can reduce the workload of equipment operation and maintenance, and reduce the input of manpower and material resources.

2) Network related skills reserve: The network-related skills reserves of the designed intelligent fusion terminal system in the distribution station area are as follows:

Layer 2 switch: Identify the MAC address information in the data packet. Forwarding is based on the MAC address, and the MAC address and the corresponding port are recorded in the internal address table.

Layer 3 switches: Layer 3 switches implement IP routing functions through a hardware switching mechanism. Its optimized routing software improves the efficiency of the routing process and solves the routing speed problem of traditional router software.

Link layer communication protocol: The data link layer provides services to the network layer based on the services provided by the physical layer. The most basic service is the reliable transmission of the source machine network layer data to the adjacent node target machine network layer.

Network layer communication protocol: The data link layer provides the data frame transmission function between two adjacent endpoints to manage network data communication. It transmits data from the source to the destination through several intermediate nodes, and provides end-to-end data transmission services to the transport layer [15].

DHCP: Dynamic Host Configuration Protocol (Dynamic Host Configuration Protocol), referred to as DHCP. It is a network protocol used in local area networks. This protocol allows servers to dynamically assign IP addresses and configuration information to clients.

DNS: Domain Name System (Domain Name System abbreviation DNS, Domain Name is translated as domain name) is the core service of the Internet. As a distributed database that can map domain names and IP addresses to each other, it makes Internet access more convenient without recording IP strings that can be read by machines.

LAN: Local Area Network (LAN) refers to a computer composed of multiple computers interconnected in a certain area.

WLAN: Wide Area Network (Wide Area Network), also known as a wide area network, external network or public network. The WAN is not the same as the Internet. It is a long-distance network that connects different local area networks or metropolitan area network computers to communicate, mainly using packet switching technology.

Docker container technology: A Linux container is a series of processes isolated from the rest of the system. All the files needed to run these processes are provided by another mirror. This means that Linux containers are portable and consistent from development to testing to production. Containers run faster than development pipelines that rely on repeating traditional test environments. Docker technology brings many new concepts and tools. It includes a simple command line interface to run and build new layered images, a server daemon, a library with prebuilt container images, and a registry server concept. Combining the above technologies, users can quickly build new layered containers and easily share containers with others.

3) Data fusion by recursive least squares: The edge computing layer of the system uses the recursive least squares method to realize the data fusion of the intelligent fusion terminal in the distribution station area. Assume that the number of smart terminals included in the distribution station area is n, and the measurement equation of smart terminal i is as follows:

$$Z_i = X + U_i \tag{1}$$

In equation (1), Z_i represents the i measurement value of the smart terminal. X represents the parameter value. U_i represents the noise value included in the data acquisition process.

The noise in the data collection process has no correlation, and the optimal weighting is based on a fixed criterion. According to the weight coefficient, the collected values of each intelligent terminal are multiplied to avoid the loss of information caused by removing the noise of data collection.

The weighting coefficient determination equation is as follows:

$$\hat{X} = \sum_{i=1}^{n} \alpha_i \times Z_i \tag{2}$$

In Equation (2), α_i represents a weighting coefficient.

The weighted estimated mean squared error equation is established as follows:

$$E = \sum_{i=1}^{n} \alpha_i^2 \delta_i^2 \times \hat{X} \tag{3}$$

In Equation (3), δ^2 represents the noise variance.

According to the conditional extreme value acquisition method of the above equation, the weighting coefficient equation that minimizes E is determined as follows:

$$f\left(\alpha_1, \alpha_2, \cdots, \alpha_n, \theta\right) = \sum_{i=1}^{n} \alpha_i^2 \delta_i^2 - \theta\left(\sum_{i=1}^{n} \alpha_i - 1\right) \tag{4}$$

In equation (4), θ represents the weight. The weighting coefficient equation is as follows:

$$\alpha_i = \frac{\delta_i^{-2}}{\sum_{i=1}^{n} \delta_i^{-2}} \tag{5}$$

The mean squared error equation to obtain the weighted estimate is as follows:

$$E\left[\left(X - \hat{X}\right)^2\right] = \frac{1}{\sum_{i=1}^{n} \delta_i^{-2}} \tag{6}$$

According to the determined optimal weights, the recursive relationship of the recursive least squares method is used to realize the data fusion of intelligent terminals in the distribution station area. The equation is as follows:

$$\begin{cases} P_{k+1} = P_k - P_k^2 / \left(1 + P_k\right) \\ \hat{Y}_{k+1} = \hat{Y}_k + P_{k+1}\left(\hat{X}_{k+1} - \hat{Y}_k\right) \end{cases} \tag{7}$$

In equation (7), $\hat{Y}_k$ and $\hat{Y}_{k+1}$ represent the data of the smart terminal at time k and $k+1$, respectively. Both P_k and P_{k+1} represent intermediate quantities. $\hat{X}_{k+1}$ represents the weighted estimated value of n intelligent terminals when time is $k+1$. Obtaining the fusion result by the recursive least squares method can ensure the minimum and unbiased estimated mean square error.

III. System Experimental Test

In order to verify the design of the large-capacity CPU with the ability of fog computing, the intelligent fusion terminal system management in the distribution station area and the effectiveness of monitoring the distribution station network. We use Matlab software to build the system in this paper, and select the distribution station area of a power company as the experimental object. The distribution station area includes distribution automation terminals, state monitoring intelligent terminals, power quality monitoring intelligent terminals, state monitoring sensors, secondary screen cabinets and many other intelligent terminals. In the distribution station area, the optical fiber network is used to realize communication.

After the system of this paper is adopted in the distribution station area, the emergency repair time when the fault occurs is calculated. The system in this paper is compared with the remote system [6] and the information fusion system [7]. The comparison results of the fault repair time are shown in Fig. 3.

It can be seen from the experimental results in Fig. 3 that the application of the system in this paper in the distribution station area can reduce the time of power failure and improve the reliability of power supply. The reliability of power supply in the distribution station area determines customer satisfaction and power supply revenue. After adopting the system in this paper, the dispatcher in the distribution station area can close the power outage switch at the first time in case of a fault, so as to reduce the outage time. It can notify the on-duty personnel to quickly repair, reduce the repair time, and improve the reliability of power supply.

At present, the residential voltage qualification rate cannot meet the residential electricity demand. The voltage qualification rate before the system in this distribution station area is not used is about 90%. After the system in this paper was applied to the distribution station area, the voltage quality of the distribution network from May to September 2019 was calculated. The method in this paper is compared with the remote system and the information fusion system. The comparison results are shown in Fig. 4.

It can be seen from the experimental results in Fig. 4 that after the system in this paper is adopted, the voltage qualification rate of the distribution station area is significantly improved. Within five months of operation, the system in this paper increased the voltage qualification rate of the distribution station area to more than 98.5%. The remote system and the information fusion system have a small improvement in the voltage qualification rate of the distribution station area, and the voltage qualification rate is lower than 95%. This system effectively monitors the voltage data of each integrated point. Through reasonable logical judgment, the comprehensive voltage regulation of the line voltage regulator is realized to ensure that the voltage of each node in the low-voltage line in the distribution network meets the voltage qualified value.

The real-time operation of the system is of great significance. The system in this paper adopts the fog computing architecture and has strong data processing and communication capabilities. Statistics The system in this paper is used to collect the refresh rate of the intelligent terminal equipment in the distribution station area. The statistical results are shown in Table I.

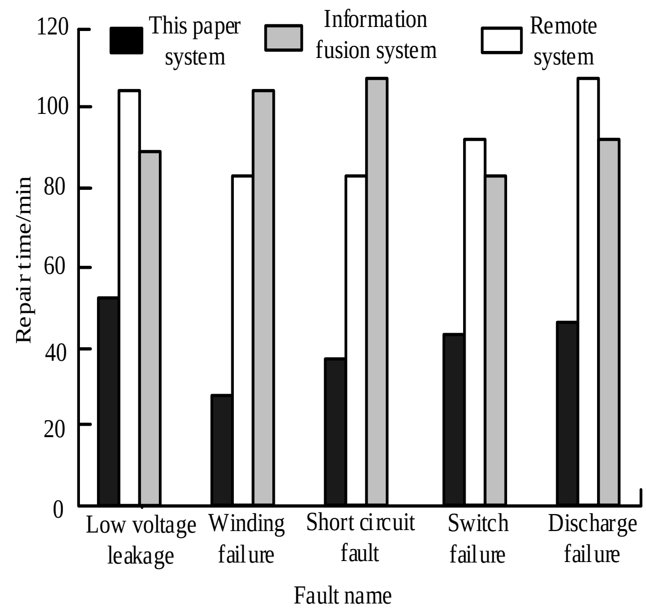

Fig. 3. Fault Repair Time Comparison.

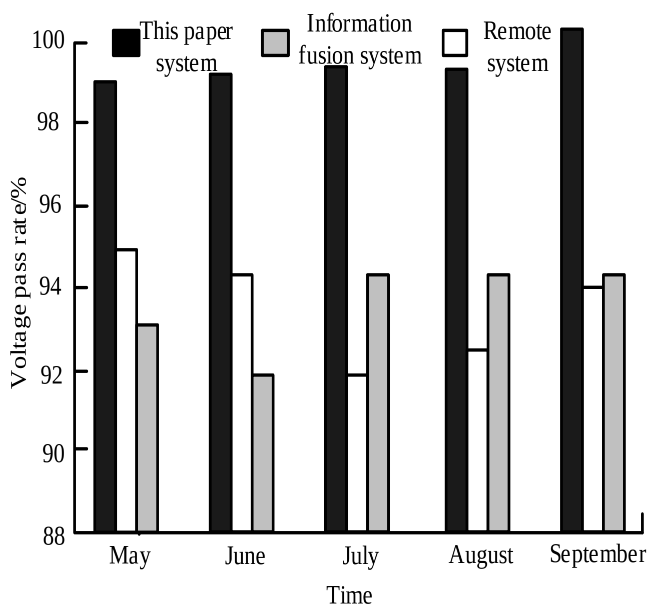

Fig. 4. Voltage Pass Rate Comparison.

TABLE I. Data Refresh Rate

System name	Fast data processing/(times/s)	Data collection/(times/s)
This paper system	120	30
Remote system	85	21
Information fusion system	94	19

It can be seen from the experimental results in Table I that the fast data refresh rate of the system in this paper is as high as 120 times/s. Intelligent terminal data collection refreshes data up to 30 times/s. The data refresh speed of the system in this paper is significantly higher than the other two systems, which verifies that the system in this paper has a higher data refresh speed. The system in this paper adopts fog computing architecture combined with large-capacity CPU, which has high communication performance and data transmission rate.

The monitoring time delay of the real-time monitoring of distribution data in the distribution station area is calculated using the system in this paper. The system in this paper is compared with the remote system and the information fusion system, and the comparison results are shown in Table II.

TABLE II. POWER DISTRIBUTION DATA MONITORING DELAY

Power distribution monitoring data name	This paper system/ms	Remote system/ms	Information fusion system/ms
Three-phase voltage	85	185	251
Electric current	91	165	234
Electrical energy	76	205	218
Tariff electricity	58	234	265
Total power	82	198	208
Voltage pass rate	94	152	234
Three-phase unbalance	84	184	218
Harmonic	76	235	269
Circuit breaker status	58	196	248
Capacitor switching state	64	184	235
Distribution terminal status	78	258	274

It can be seen from the experimental results in Table II that the monitoring delay of the system in this paper is less than 100ms. Using remote system and information fusion system to monitor the distribution of data monitoring delay in the distribution station area is higher than 150ms. The power distribution data monitoring delay of the system in this paper is significantly lower than that of the other two systems. The main reason is that the system in this paper adopts a fog computing architecture and a large-capacity CPU, which effectively improves the data processing capability of the system. The system meets the data acquisition and monitoring needs of the distribution station area.

Statistical data processing efficiency under different data volumes: The system in this paper is compared with the other two systems, and the comparison results are shown in Fig. 5.

As can be seen from the experimental results in Fig. 5, the data processing efficiency of the system in this paper is higher than 97% under different data volumes. The data processing efficiency of the other two systems is lower than 96% in the case of different data volumes. The fog computing architecture adopted in this system has high data processing efficiency. The previous cloud computing platform needs to transmit all the collected data to the computing center, and use the computing center to process the data, which cannot meet the delay requirement. The fog computing architecture can realize the analysis of data collected by the edge computing unit and improve the efficiency of data processing. The fog computing architecture can meet the low latency requirements of power communication networks. In the face of massive power data, it has high processing efficiency and can be used as a good solution in the distribution network.

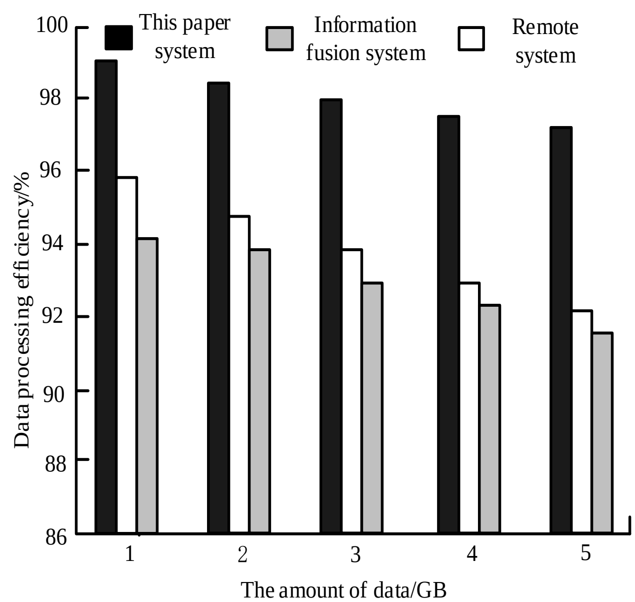

Fig. 5. Data Processing Efficiency Comparison Results.

After adopting the system in this paper, the cost of investing in secondary equipment in the distribution station area is calculated. The system in this paper is compared with the other two systems, and the comparison results are shown in Table III.

TABLE III. SECONDARY EQUIPMENT INVESTMENT ANALYSIS

Project	This paper system/million	Remote system/million	Information fusion system/million
Distribution automation terminal	3.5	4.2	4.3
Power quality monitoring terminal	2.4	2.6	2.5
Condition monitoring sensors	1.9	2.2	2.3
Condition monitoring unit	1.8	1.9	2.1
Fiber optic communication unit	0.9	1.1	1.1
Secondary screen cabinet	0.7	0.9	0.8
Total	11.2	12.9	13.1

From the experimental results in Table III, it can be seen that after using the system in this paper, the cost of investing in secondary equipment in the distribution station area is lower than the 17,000 yuan of the remote system and the 19,000 yuan of the information fusion system. The experimental results show that the system in this paper has a higher management effect of power distribution equipment. Applying the system in this paper to the distribution station area can effectively save the investment cost. It has high performance of intelligent terminal management in power distribution station area, which is helpful for the long-term development of electric power enterprises.

IV. Conclusion

Power grid technology has developed rapidly, and power infrastructure has been gradually improved. The primary and secondary equipment of the distribution network has gradually matured and stabilized. There are many intelligent terminals installed in the distribution network station area. Through the intelligent terminals, the power distribution data collection in the distribution station area and the online monitoring of the power consumption data can be realized. However, the functions of comprehensive management, comprehensive analysis and comprehensive control in the distribution station area are not perfect. We combined the fog computing mechanism with the large-capacity CPU to design an intelligent fusion terminal system in the distribution station area with fog computing capability based on the large-capacity CPU. And it is verified by experiments that the system has high practicability in the distribution station area. The researched system has a high level of automation and low input cost, which can help power companies to complete the goal of smart grid construction and realize smart grid functions. In the event of a power outage in the distribution station area, the researched system can transmit the terminal fault information data back to the system. The system sends information to equipment maintenance personnel. After receiving the information, the maintenance personnel can quickly reach the fault location, and the repair speed is fast, which improves customer satisfaction with electricity consumption.

V. Declaration

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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References

[1] Liu D Q, Zeng X J, Wang Y N. Security Situation Assessment of Intelligent Distribution Transformer Terminal Unit Based on Information Entropy[J]. Southern Power System Technology, 2020, 121(01):24-29.

[2] Ji Q H, Wei Z, Wang T, et al. Research on the Control Strategy for Three-phase Unbalanced Load in Distribution Area[J]. Power Electronics, 2020, 327(02):38-40+52.

[3] Li Y X, Lu J, Xu Z Q, et al. Design of Terminal Communication Access Architecture for Smart Power Distribution and Utilization Based on Integration of Multiple Technologies[J]. Automation of Electric Power Systems, 2018, 632(10):169-175.

[4] Liu T, Tang L, He X Q, et al. Optimal Task Offloading Scheme Based on Network Delay and Resource Management in Joint Blockchain and Fog Computing System[J]. Journal of Electronics & Information Technology, 2020, 42(09):2180-2185.

[5] Wang C L, Huang X T. Study on Optimal Allocation of Inference Nodes for Fog Computing in Smart Environment[J]. Acta Electronica Sinica, 2020, 048(001):35-43.

[6] Qi E J, Peng D G, Guan X L, et al. Design of the Remote Terminal Data Acquisition System for the Intelligent Distribution Automation[J]. Electric Drive, 2018, 345(07):62-67.

[7] Chen F J, Lv Y S, Fan G S, et al. Automatic test system of relay protection device for smart substation based on information fusion technology[J]. Power System Protection and Control, 2020, 551(05):164-169.

[8] Cong W, Sheng Y R, Xian G F, et al. Distributed Power Service Restoration Method Based on Smart Terminal Unit[J]. Automation of Electric Power Systems, 2018, 637(15):83-91.

[9] Fu J, Ji R Y, Wang D, et al. Research and Application of Distribution Network Courts User' 's Behavior Analysis Model Based on Parallel K-Means Clustering[J]. Power System and Clean Energy 2018, 034(011):71-76.

[10] Ma W, Shao C X, Liu M Z. Study on content access of fog computing in highway service area[J]. Application of Electronic Technique, 2018, 44(012):101-105, 110.

[11] Liu L, Zhao G Q. Intelligent Incentive Mechanism for Fog Computing-based Multimedia Systems with Swarming Behavior[J]. Computer Science, 2019, 046(011):94-99.

[12] Ou Z Z, Zhao H J, Zhu L J, et al. Research on the Method for Three-phase Load Balancing and Reactive Power Compensation in Distribution Areas[J]. Power Electronics, 2019, 317(04):101-104.

[13] Xiong J Y, Yang G P, Guo Y, et al. Compatibility Analysis of ECT and EVT in Primary & Secondary Fusion of Intelligent Power Distribution Equipment[J]. Power Capacitor & Reactive Power Compensation, 2019, 40(01):114-120.

[14] Liu R L, Liu H T, Xia S F, et al. Internet of Things Technology Application and Prospects in Distribution Transformer Service Area Management[J]. High Voltage Engineering, 2019, 319(06):33-40.

[15] Wu S, Hao S P, Yang L X, et al. Information model and application of intelligent distribution area based on CIM[J]. Electrical Measurement & Instrumentation, 2018, 55(10):52-57+95.