A software and hardware design of intelligent measurement and control terminal of distribution network based on a communication adaptive approach

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Abstract. With the development of science and technology, the hardware and software design of transformer intelligent measurement and control terminal is very important. Based on the hardware and software appization of internet of things, the design scheme of hardware and software structure is given. Supported by high-performance operating system, the terminal device can be upgraded flexibly through APP application software. The intelligent terminal pair can realize full data collection, full control and full fusion, and real-time exchange of key operation data with the power distribution master station. The intelligent terminal can support 5G communication and realize full compatibility of communication conditions downward.

1. Introduction
Since the 21st century, the construction of power grid infrastructure has been increasingly improved, the grid architecture has become stable and mature. In order to further improve the quality of power supply service, meet the power demand of users and optimize the allocation of resources, countries around the world have also put the goal of popularizing smart power grid [1]. Smart power grid is a new power grid system that combines advanced power electronics, information communication, computer and other technologies with traditional power grid facilities, which is to realize intelligent and information-based operation of power grid. With the rapid development of information technology, digital technology, Internet of Things technology and new energy power generation technology in recent years, the transformation and upgradation of the energy and power industry is necessary.

The construction of smart grid is still faced with the restriction and challenge from the aspects of distribution system upgrade, automation of distribution station and intelligent instrument. As an important link of power transmission and power network information acquisition, the safety and reliability of power distribution network have an important influence on the operation of power network and the production and life of residents [2]. With a large number of monitoring devices, EV charging piles, distributed power supply and other access, field equipment of distribution network increased
greatly, but at the same time, there are also problems of weak structure and low management level. In order to meet the new and diversified demands of users, the transformation and upgrading of distribution network has become an urgent task at present [3]. As an important part of distribution network, distribution station is the end link of power system composed of distribution transformer and other distribution equipment, which undertakes the task of changing voltage and supplying power to users. To complete the transformation and upgrading of distribution network, it is necessary to realize the effective monitoring and management of medium and low voltage distribution network. At present, distribution automation mainly realizes the operation control of medium-voltage distribution network, and lacks the unified monitoring and operation control means for low-voltage distribution network.

In recent years, with the rapid development of Internet of Things technology and the continuous improvement of industrial production demand for intelligence and refinement, the Internet of Things has been more widely applied in the field of industrial production [4]. Therefore, it is imperative to build an intelligent and networked distribution center network based on the Internet of Things and a system, which realizes intelligent and efficient state perception and operation control of low-voltage distribution network.

The distribution station can be equipped with all kinds of sensors with high precision, high reliability and low power consumption to realize real-time acquisition of electric quantity parameters such as voltage, current, power, frequency and other non-electric quantity information, such as temperature and humidity, and breaker switching state. Hardware design from the core control, communication interface and functional implementation of three levels. With distribution transformer center network as the core, the technical support system of distribution power station based on Internet of Things architecture is constructed. The system composition and support technology are discussed from the perspective of perception layer, network layer, platform layer and application layer.

The embedded Linux high performance processor should greatly improve the edge terminal intelligence level [5] and edge computing level [6]. Based on the embedded Linux operating system, the software design based on the USES container technology to realize the app-oriented software to realize the terminal state awareness and intelligent control.

Communication system is a key link in the construction of intelligent distribution network [7]. Meanwhile, with the construction of 230 MHz power wireless private network and 5G network, new communication methods are gradually applied. The ability to communicate has been greatly enhanced. Big data, artificial intelligence and “cloud+ terminal” computing mode make the value of data fully play. These advanced sensor technology, control technology and computer network communication technology of the Internet of Things have laid a solid foundation for the construction of the technical support system of distribution stations. We need to design distribution intelligent measurement and control terminal based on the Internet of Things architecture to realize comprehensive perception of distribution station information and improve local data analysis and decision-making ability. At the same time, taking intelligent measurement and control terminal as the core, it has important theoretical and practical significance to study the technical support system of distribution station.

The content of the paper is outlined as follows. The Section 2 discusses the characteristics and development direction of the traditional distribution transformer terminal. Section 3 gives Overall analysis of intelligent measurement and control terminal with configuration and transformation. In section 4, we give the hardware design of intelligent measurement and control terminal based on hardware platform. Section 5 shows the design of intelligent measurement and control terminal software based on “software appization”. Moreover, paper is concluded with some discussions and closing remarks.

2. Analysis of traditional distribution terminal
In the traditional power supply and distribution system, the distribution transformer supervisory terminal (TTU) is mainly used to realize the state detection and control of the distribution transformer. The main functions of traditional TTU are data acquisition, simple control and communication, and its typical working principle is shown in the Figure 1.
In terms of hardware structure, with the improvement of operation and maintenance requirements of distribution network and the continuous increase of distribution network business, it is difficult for traditional distribution terminals to meet the requirements in hardware. The computing and storage performance of the core processor chip used in the system cannot meet the design requirements of the new configuration and transformer terminal, and the hardware modularity to realize each function is poor, it is difficult to realize flexible configuration and expansion.

In terms of software structure, the traditional configuration terminal software design generally adopts the way of curing to hardware, and the flexibility is poor. Traditional software is difficult to realize late maintenance and function expansion, which may lead to the increase of business requirements and the need to reinstall the corresponding category of equipment, as well as the repetitive information collection, scattered location of equipment, and increasingly complex management. In addition, long-term use of traditional software will bring great pressure on equipment operation and maintenance.

In terms of communication mode selection, carrier communication and RS485 communication are the main communication modes under the traditional distribution transformer terminal pair, and GPRS and Ethernet communication are the main communication modes above. The communication mode is relatively single and the communication reliability is poor. The construction of the technical support system of distribution station will be connected with a large number of equipment and widely distributed, so the traditional communication mode is difficult to meet the construction requirements.

3. Overall analysis of distribution and transformation intelligent measurement and control terminal

3.1. Demand analysis

The upgrading of distribution network has put forward higher requirements for the monitoring of state information of low-voltage distribution stations, and the traditional distribution terminal has been unable to play its role. Therefore, intelligent measurement and control terminal needs to be designed to meet the growing control requirements of distribution stations.

As the core and basic equipment of the distribution station technical support system, the function of intelligent measurement and control terminal is to complete data acquisition, processing and transmission. Therefore, distribution and transformation intelligent measurement and control terminal mainly has three requirements: comprehensive data collection, local processing and analysis and reliable transmission.

Because the function design of the traditional distribution terminal generally adopts the way of curing to the hardware, so the flexibility is poor. Once it is deployed to the field, it is difficult to realize the late maintenance and function expansion. To solve this problem, this paper carries out the overall design of intelligent measurement and control terminal based on the technical architecture of “Internet of Things”. The decoupling of hardware and software is realized by adopting the design idea of “hardware platform and software appization”, and the difficulty of application extension of traditional distribution transformer terminal is solved. At the same time, the Internet of things technology is used to realize multi-sensor networking and communication, and edge computing technology is used to realize data
analysis and decision making of distribution stations under different circumstances, so as to meet the new requirements of operation, maintenance and control of low-voltage distribution stations.

3.2. Integrated design of intelligent measurement and control terminal

The configuration and transformation of intelligent measurement and control terminal is based on the architecture design of “Internet of Things”, and embedded system is one of the core technologies of the Internet of Things. Firstly, the structure of typical embedded system is introduced. On this basis, the overall design of intelligent measurement and control terminal is carried out. Typical embedded system architecture is shown in Figure 2.

![Diagram of Typical Embedded System Structure](image)

**Figure 2.** Typical embedded system structure

The structure of typical embedded system is divided into hardware and software. The hardware part includes embedded processor and peripherals, and the software part includes operating system and application software.

The overall design of intelligent measurement and control terminal can be divided into three parts: hardware layer, system layer and APP layer. The hardware layer corresponds to the hardware part of the embedded system structure, and the hardware platform composed of ARM processor and peripherals serves as the operation support platform of intelligent measurement and control terminal and the operation carrier of embedded software system. The system layer and APP layer correspond to the software part of the embedded system structure. The embedded Linux operating system used by the adapter intelligent measurement and control terminal has the same purpose as the operating system used by the computer. They are designed to mask underlying hardware differences, provide a unified interface for application software development, and allow developers to focus on the implementation of application functions. Application APP development used edge computing technology to realize data fusion and analysis and decision at the data source. This not only improves the terminal edge computing capacity and intelligence level, but also benefits the safe and economic operation and management of distribution stations. Intelligent measurement and control terminal adopts the architecture design of The Internet of Things, and uses the sensor networking mode of the Internet of Things to achieve multi-
sensor and equipment access to the distribution station network, and is compatible with the wireless communication mode and communication protocol of the Internet of Things, which makes the network structure flexible and changeable. The embedded Linux kernel is transplanted on the basis of unified ARM processor. Install common components on the Linux kernel, and implement the installation and operation of the application APP through the unified call interface. The overall design realizes the decoupling of hardware and software, the decoupling of operating system kernel and common components, and the decoupling of software system and applications, which is conducive to the unified management of terminals and flexible configuration of business functions. This fully reflects the "hardware platform, software appization" design ideas.

4. Hardware design of intelligent measurement and control terminal based on hardware platform

The hardware design of intelligent measurement and control terminal is expanded from the core control layer, communication interface layer and function realization layer to build a unified hardware platform.

4.1. Hardware architecture

The hardware design is first carried out around the core CPU, and the core board of ARM Cortex-A77 chip is selected as the core control layer in this paper. The chip is powerful and can meet the requirement of high performance and high reliability of intelligent measurement and control terminal. In the core control layer, CPU chip is configured with SDRAM and NAND Flash memory chips with fast read and write speed. Meanwhile, unused pins are drawn out from the core board for communication interface layer and function implementation layer. Reference ARM Cortex-A77 chip pin function design required communication interface, such as RS 485, USB, Ethernet, etc. When we design the functional unit layer of intelligent measurement and control terminal, we should pay attention to that the functional unit layer includes information acquisition unit, switching input and output unit, device management unit and human-computer interaction unit, etc., and conduct data and information interaction through the communication interface layer.

4.2. Core control layer hardware design scheme

The program execution ability and data processing and analysis ability of intelligent measurement and control terminal mainly depend on the performance of core CPU. The CPU used in the hardware design must have a rich communication interface, so that it can be equipped with other functional modules as needed. ARM Cortex-A77 has a master frequency of up to 3GHz, which can meet the performance and interface design requirements. Meanwhile, it is equipped with embedded Linux system to adapt to the development trend of app-based application development.

Safe and stable power supply is required for the normal operation of intelligent measurement and control terminal. The power management module shall not only ensure the power supply of the intelligent measurement and control terminal during normal operation of the distribution station, but also provide normal power supply after the failure of the distribution station. The power supply system adopts ac and DC. During the normal operation of the distribution station, the low-voltage side of the distribution transformer provides 220V alternating current, which is delivered to the power management module after the step-down of AC/DC to obtain 12V direct current. On the one hand, DC/DC voltage conversion is applied to power the intelligent measurement and control terminal, and on the other hand, it is used to charge the lithium battery. When the distribution transformer fails to provide alternating current due to some faults in the distribution station, the lithium battery shall provide power supply for the intelligent measurement and control terminal through the power management module to ensure its continuous operation.

The core control layer also includes SDRAM and NAND Flash, which constitute the core storage area of intelligent measurement and control terminal. SDRAM stores the intelligent measurement and control terminal operating system and applications, as well as buffers for related read and write data. NAND Flash is a non-volatile storage device. Its advantage is that the stored content will not be lost.
when the terminal is unexpectedly cut off, and its storage density is high and its writing erasable speed is fast. Therefore, NAND Flash can be used to store applications, system codes and relevant data collected and generated by intelligent measurement and control terminal with configuration and transformation.

4.3. Communication interface layer hardware design scheme

Intelligent measurement and control terminal is the basis and core equipment of the technical support system of distribution station, and its function is to collect, analyse and transmit data of distribution station. Rich communication interface is a solid support for data interaction, and also an important embodiment of the design principle of “hardware platform”. Based on the core control layer, this paper designs the communication interface layer from two parts: local communication interface and remote communication interface.

(1) Local communication interface

The local communication interface of distribution and transformation Intelligent measurement and control terminal is used to complete the communication between distribution and transformation Intelligent measurement and control terminal, distribution station perception terminal and distribution equipment, or as human-computer interaction interface. RS232 / RS485 is the mainstream communication mode of electronic equipment. In order to improve the communication capability of Intelligent measurement and control terminal, the local communication interface designed in this paper also includes Zigbee, USB, broadband power line carrier and Ethernet, etc.

(2) Remote communication interface

The remote communication interface of intelligent measurement and control terminal is used to complete the data transmission and information interaction with the distribution cloud master station. Considering with the Intelligent measurement and control terminal installation environment difference, this article provide Ethernet communication and 5g communication two kinds of communication mode, according to the environment to choose the appropriate way to complete the remote communication.

Ethernet communication interface is used for remote communication. It has the advantages of high transmission rate, stable communication and convenient configuration. With the maturity of 5G technology and the construction of 5G base station, 5G communication will become an important way of long-distance communication between intelligent measurement and control terminal and master station. ARM Cortex-A77 supports 5G rapid deployment, and 5G modules extended on the core control layer have significant advantages of high speed, low latency and low power consumption.

4.4. Function realization layer hardware design scheme

Function realization layer is an important support for intelligent measurement and control terminal monitoring and optimal control of distribution station operation conditions. This section mainly designs hardware scheme from four parts: information acquisition unit, switching input and output unit, device management unit and human-computer interaction unit.

(1) Hardware design of information acquisition unit: The power distribution station information acquisition mainly includes AC sampling, status monitoring sensor, video surveillance camera, concentrator and intelligent electricity meter.

(2) Hardware design of switching input and output unit: The function of switch input and output circuit is to detect the closed state of related switch in distribution station and control the output to make the switch operate. Transformer Intelligent measurement and control terminal mainly realizes the acquisition of signals such as the position and status of transformer low-voltage main circuit breaker, the opening and closing status of cabinet door and the position of low-voltage feeder switch. The state quantities of these switches are directly sent to the GPIO pins of the core control layer after photoelectric isolation, and the state of the switch is judged by the high and low level signals input by GHO. The switching output circuit controls the relay action by controlling the pin level of the main control chip to complete the switching operation.
(3) Device management unit hardware design: The equipment management unit mainly completes the information interaction with intelligent capacitors, three-phase unbalanced treatment equipment, charging monitoring equipment and distributed power supply monitoring equipment, and completes the equipment control according to the corresponding instructions of local and master stations.

(4) Human computer interaction unit hardware design: The human-computer interaction unit of intelligent measurement and control terminal includes LCD, LED, mouse, keyboard and USB flash disk. The LED indicator light is connected with the GPIO pin to indicate the working status of power supply, control signal, energy metering, communication, etc. The TFT interface is connected to the LCD screen as the display unit of the intelligent measurement and control terminal. By connecting mouse and keyboard through USB interface, the operation and maintenance personnel can operate in a simple and convenient way, and the U disk can be used to copy local data and copy and upgrade the system image.

5. Hardware design of intelligent measurement and control terminal based on hardware platform

5.1. Software architecture

The configuration intelligent measurement and control terminal software structure is based on the tailored Linux operating system and virtualization container technology. The functions of the configuration intelligent measurement and control terminal are developed, managed and run flexibly in the form of an independent APP, which effectively improves the reliability and expansibility of the system. The configuration intelligent measurement and control terminal software structure based on embedded Linux system mainly consists of driver, kernel and application program. 1

The driver layer of the software system develops the drivers of various hardware access devices and completes the access of communication modules, processor peripherals and other devices. The Linux kernel manages all the hardware peripherals connected to the system down through the driver, and provides a unified interface up for the application layer to call. The application layer mainly consists of some user-oriented applications and libraries that run the configuration intelligent measurement and control terminal software functions on the Linux operating system. The software architecture is shown in Figure 3.

![Software architecture of intelligent measurement and control terminal.](image)

5.2. Linux kernel analysis

In the operating system, the kernel mainly allocates the memory space, network connection and other resources to each application program that needs to be executed, and the cooperation among each submodule in the kernel ensures the stable operation of the system and the realization of application functions. The Linux kernel consists of five submodules:
(1) Process Scheduler: Multiple processes running on the system need frequent access to the CPU, and process management controls how different processes access the CPU to ensure a reasonable allocation of system CPU resources.

(2) Memory Manager: Processes in the system not only have frequent access to the CPU, but also use the system's memory resources. The memory management module is responsible for the rational allocation of memory resources.

(3) Virtual File System: In the Linux operating system, all hardware devices are abstracted into file systems, such as storage devices, display devices, etc. The Linux kernel realizes the access to different devices through the unified file operation interface.

(4) Device Management: The access and control of the embedded system to all external devices should be realized through the driver program. The access of hardware devices on the software level can be realized through the driver program. The operation of hardware devices can be finally realized through the driver program.

(5) Network: Different network protocol standards are implemented to manage the network devices connected to the system.

5.3. The key technology of software APP

In order to realize the “software appization” of the configured Intelligent measurement and control terminal, it is necessary to independently develop, install, run and maintain the functions to be implemented by the configured Intelligent measurement and control terminal in the form of APP on the basis of the embedded Linux operating system kernel, make full use of the virtualization container technology and learn from the concept of mobile phone APP.

(1) Concepts and characteristics of container technology

Container technology refers to the virtualization technology that packages the system's applications, data and running environment into container images for application development, migration, deployment and running.

(2) Container technology application strategy

On the kernel of Linux operating system, container technology is used to independently deploy business applications, so that each application can be independently formed into different apps without affecting each other. Any distribution station can make use of local rich data resources combined with edge computing technology to achieve edge decision-making and autonomy.

(3) APP business interaction mechanism

The APP business interaction of intelligent measurement and control terminal mainly includes information interaction between APPS and APP data storage access. The information interaction between APPS is based on the bus mechanism. According to the principle of loose coupling of message access, the decoupling of data interaction can be realized to avoid the management difficulties caused by private interaction. A centralized database was established in the configuration and transformation Intelligent measurement and control terminal, and centralized storage and unified management of all types of data in the configuration and transformation Intelligent measurement and control terminal were carried out by the centre, so as to prevent the logical chaos and storage resource waste caused by the establishment of private database for each APP. In the process of APP development, unified external interfaces should be reserved to realize convenient information exchange between different APPs.

5.4. Terminal “edge computing” technology

Based on distribution and transformation Hub Net, the edge meter gathers and stores the information collected by sensors and other sensing devices. Meanwhile, an APP is used for edge processing and analysis of distribution station data to make local decisions. In this way, the overall perception ability and local autonomy level of distribution station can be improved.

The edge computing layer mainly realizes device access, protocol conversion, edge data processing and other functions. Device access refers to the connection of field devices and sensors to adapter intelligent measurement and control terminal based on serial port, RS485/232, ZigBee, LoRa, WiFi,
Ethernet, etc. Protocol conversion refers to the use of protocol parsing and other technologies to develop device driver SDK to achieve the compatibility of communication protocols and interfaces of various field devices and realize the unification of data formats at the edge. Edge data processing refers to the application of edge analysis APP encapsulated in a container on the basis of ARM Cortex-A77 core processor and Linux operating system to achieve data aggregation, storage and processing analysis on the configured intelligent measurement and control terminal to reduce data processing delay and network transmission pressure.

Configuration and transformation intelligent measurement and control terminal should establish a unified model, local self-management database, the database to achieve the storage and management of a variety of types of data. In addition to distribution monitoring data, there are also collected environmental data and data processed by APP. Therefore, the database should establish a unique data reading and writing channel, and the data storage access of each APP should be conducted through a unique channel, so as to improve the convenience of data management.

6. Conclusion
In this paper, the characteristics and development direction of the traditional distribution substation terminal are described: based on the distribution station scene, the demand analysis of distribution substation intelligent measurement and control terminal is carried out. The overall design is based on the architecture of “Internet of Things”. The hardware structure and software structure are designed with the design idea of “hardware platform and software appization”, which solves the problem that the application of traditional distribution transformer terminal is difficult to expand and meets the requirements of the technical support system construction of distribution power station.

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