Open Architecture Design of Universal Terminal for Multiple Measurement and Control Scenarios of Distribution Network

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Abstract. Introduce the IoT platform technology based on SDN (Software Defined Network), cloud-based, flexible management and configuration of smart terminals, and support access to millions of terminal devices and smart operation and maintenance management. The traditional monitoring system is integrated with the Internet of Things platform, and on the basis of realizing the general SCADA system monitoring function, through the side-cloud collaboration, the lean management of the distribution station area is realized.

1. Introduction

Distribution automation system is widely constructed and applied in various provinces, which promotes the automation, informatization and intellectualization of the distribution network. However, due to the lack of technical means and management measures, the low-voltage distribution network, as the "last kilometer", has been in the monitoring blind area for a long time. There are many problems, such as various terminal types, low intelligent level, non-standard standards, diverse communication protocols, etc. The distribution area operation and maintenance, equipment monitoring, asset management, customer service experience and other aspects need to be improved [1]. At the same time, with the continuous expansion of distribution network scale and the deepening of energy revolution pilot projects of power reform, comprehensive energy, incremental distribution, the massive intelligent terminal puts forward higher requirements for the breadth, frequency and depth of data acquisition. The distribution network has gradually upgraded from the previous power transmission and customer service to the distribution IOT stage of data holographic perception, data collaborative fusion and application intelligent service, which provides new ideas, new models and new formats for the construction of distribution network.

At the system construction level, the traditional distribution automation SCADA system, as the basic platform of the distribution automation system, is responsible for monitoring the real-time operation status of the whole distribution network and collecting the operation data of various equipment. At the same time, the application of distribution SCADA is more and more, and the distribution network is facing many challenges. At present, the low-voltage distribution network is often managed by the area...
(usually called the distribution station area) with the power supply scope of distribution transformer as the unit. The network in the substation area needs to realize independent comprehensive management and control, business two-way interaction, ensure the reliability and quality of power supply, and realize the lean management and control of low-voltage distribution network. The distribution IOT will play an important role in promoting the new ecology of power system in terms of standardization, digitalization, business software definition and so on.

At the level of network construction, there are many distribution network equipment manufacturers, and different manufacturers do not follow the unified data model specification and communication protocol, which leads to the confusion of data management and the complexity of information network. We need to formulate a unified data model specification and communication protocol to eliminate the information island and realize the unified management of data. The existing communication infrastructure, especially the local communication, has great limitations in supporting the distribution business. The communication bandwidth, speed, delay and reliability are difficult to meet the requirements of real-time transmission and interaction of large amounts of data in distribution station area. The distribution IOT can introduce the concept and key technologies of SDN to realize the plug and play of terminal equipment.

In terms of terminal construction, the traditional intelligent terminals of distribution network include feeder monitoring device (FTU), distribution monitoring device (DTU) and intelligent electricity meter. Most of them are designed separately to realize a specific function, and the functions are preset in advance and relatively fixed. The equipment interface and service architecture of various manufacturers are difficult to be compatible and interchangeable, and the upgrade is not flexible enough. The massive measurement data of intelligent terminal put forward more stringent performance requirements for data storage, transmission and processing. The intelligent terminal of distribution IOT is terminal of communication gateway and data integration, which requires strong data processing ability, efficient information interaction ability and business plug and play expansion.

This paper introduces the SDN concept, based on the IOT platform technology, combined with the characteristics of low-voltage distribution network, puts forward the design concept, system architecture, key technologies and collaborative mechanism for multi measurement and control scenarios of distribution network; selects the application practice of plug and play of low-voltage equipment to demonstrate the effectiveness of the technology, and finally summarizes and prospects the future development prospects of distribution network.

2. SDN architecture
Software defined network (SDN), as a new network innovation architecture, uses openflow and other core technologies to realize the separation of network control plane and data forwarding plane, which can realize the effective control of data flow, virtualization of underlying devices and network programmability. Users can realize the logic centralized control of the whole distribution network, the efficient management of distribution network resources and the software programming of various terminal equipment configuration through SDN technology. These characteristics provide a good idea for solving many difficulties encountered in the development of the current distribution network.

There are a variety of SDN architecture solutions, including: ONF, SDN architecture defined from user dimension; NVF (network functions virtualization) architecture proposed by European Telecommunication Standards Association from network operator dimension; and open source project architecture jointly launched by Cisco, Microsoft, IBM and other companies [2].

2.1. ONF SDN architecture
ONF hopes to promote rapid business innovation through network abstraction. From the user dimension of network resources, SDN architecture is mainly infrastructure layer, control layer and application layer. The control layer is mainly responsible for the deployment and configuration of data plane resources, network topology architecture and related state information. The infrastructure layer is mainly responsible for data processing, forwarding and state collection. The application layer is mainly
responsible for the application of various business fields of the system [3]. The control layer and the infrastructure layer are connected by the north interface, and the application layer is connected by the south interface. The SDN architecture of ONF is shown in Figure 1.

![Figure 1. The SDN architecture of ONF](image)

2.2. **ETSI NFV architecture**

From the dimension of network function virtualization, the European Telecommunication Standards Association proposed NFV standard architecture, including NFVI (nfvi infrastructure), management, arrangement, VNFs and so on, which is shown in Figure 2.

![Figure 2. ETSI NFV standard architecture](image)

NFVI includes virtualization layer and physical resources. NFV is mainly responsible for deploying network functions on general hardware. VNF corresponds to specific virtual network. The important role of "overall management and arrangement of NFV" is to undertake 3 major functions, include "NFV arrangement", "VNF management" and "virtualization infrastructure management". The typical
applications are open source Openstack and commercial version VMware. VNF management controls the life cycle of VNF according to its description. Although SDN controller is not listed in the reference framework, SDN controller should be able to support automatic resource scheduling of physical network and virtual network, be compatible with the transmission of overlay network and multi-layer data flow, and adapt to the data bridge between SDN and non SDN network.

3. System architecture

Combined with the overall architecture of distribution IOT, this paper studied the key technologies suitable for general terminal opening and proposed the distribution IOT system architecture based on SDN architecture.

3.1. Architecture of distribution IOT

With the continuous development of IOT technology, especially the maturity of intelligent sensor, low-power wide-area network (LPWAN), 5g, cloud computing, edge computing and other technologies, the technology integration of distribution network and IOT can realize the value discovery of big data in distribution side. The IOT platform is usually divided into perception layer, network layer, platform layer and application layer, which realize the functions of data acquisition, data transmission, data processing and data analysis.

In 2019, State Grid Corporation of China (SGCC) proposed the ubiquitous power Internet of things (UPIoT) with comprehensive construction state perception, efficient information processing, and convenient and flexible application. It fully applies modern information and communication technology to realize interconnection and human-computer interaction in all aspects of power system [4]. The distribution IOT is just the application embodiment of UPIoT in the field of distribution, and has become the key element to reshape the operation and maintenance mode of distribution station area. Through the global identification of low-voltage terminal equipment and extensive interconnection between equipment in distribution network, the distribution IOT realizes the holographic perception of data, collaborative data fusion and application intelligent services of distribution network, and promotes the "three streams in one" of energy flow, business flow and data flow on the distribution side. The overall architecture of distribution IOT is shown in Figure 3.

![Figure 3. The overall architecture of distribution IOT](image-url)
Among them, "cloud" is the main cloud station. Through the innovation of traditional information system architecture and organization, it can realize the functions of ubiquitous interconnection, open application, collaborative autonomy and intelligent decision-making. "Management" is the data transmission channel, which has the characteristics of real-time, high-efficiency and security. "Edge" is a distributed intelligent agent close to the data source and at the edge of the network, which expands the scope and ability to collect and manage data of "cloud". "End" is the main terminal unit of state perception and executive control in the distribution IOT architecture. The most important is the cloud master station and edge computing intelligent terminal of distribution IOT.

3.2. Open architecture of distribution station area based on distribution IOT technology

In terms of internal business, the distribution station area needs to introduce a new type of computing and network architecture, so that the operation status of the distribution station area itself and all the low-voltage distribution networks under its jurisdiction can be local online monitored, intelligent analyzed and decision-making controlled, alleviate the huge pressure of full coverage high-frequency data acquisition on communication, storage and calculation, and improve the operation and maintenance service speed and quality of the station area.

In terms of external business, it provides data sharing and technical services to the government, enterprises, scientific research institutions and other entities through intelligent resource collaboration between cloud master station and edge computing node.

Based on the concept of software definition, absorbing the ubiquitous perception and IP communication characteristics of the Internet of things, integrating the distributed intelligent architecture of distribution network, introducing the concept of distributed intelligent collaboration combining cloud computing and edge computing to realize the comprehensive perception and supervision of distribution network and assets, this paper proposes a general open architecture for distribution station area design based on distribution Internet of things technology.

The general open architecture aims to achieve the following goals:

(1) Business system software definition

In order to efficiently integrate massive distribution network resources and meet diversified business integration and rapidly changing service requests, the distribution station area takes the general open organization structure based on software definition as the basic form of the new business system. The purpose of software definition terminal is to provide general software platform to meet the ever-changing application requirements of distribution station area without hardware change; software defined network separates network topology from network control to meet the needs of adjustment and expansion of communication resources; the purpose of software definition master station is to provide various kinds of platform micro services oriented to software definition, and support the rapid deployment and iterative application for business of master station. In addition, a unified business application development and management environment should be established to ensure the unified specification of business applications, and support the third-party manufacturers to develop adaptive micro applications for distribution stations. It can support the network management of business applications, support the massive device connection of more than millions of terminals, and realize resource elastic management, distributed deployment and smooth expansion.

(2) Overall perception of low voltage distribution network

Through the access, transformation or deployment of intelligent primary equipment, secondary equipment and intelligent sensors at the distribution transformer side, feeder side and user side, all kinds of basic data collection of low-voltage distribution network can be realized. At the same time, based on broadband carrier IP and micro power wireless communication, the concept of SDN is introduced to build a unified communication interface and interaction model, so as to solve the problems of large amount of low-voltage intelligent equipment, scattered location, wiring and maintenance difficulties, and realize ubiquitous interconnection of equipment.

(3) Local control of data and application
The total data control in the station area needs local control, and the quantity type and total amount generated by the distribution station area will continue to grow. If all monitoring data are uploaded to the master station, it will consume a lot of communication resources and master station resources, resulting in a great waste of resources. In practical application, a large number of normal operation data do not need to be uploaded to the master station. At the same time, the rapid analysis and decision-making of the substation area needs local management and control, and some business control and implementation require high real-time performance, such as distribution transformer protection, fault research and judgment, etc.

3.3. Function design of distribution IOT

3.3.1. Cloud master station of distribution IOT. The cloud master station of the distribution IOT realizes the functions of mass device connection, plug and play of terminal equipment, fast online application, multi-source data fusion, edge cloud collaboration, distribution network monitoring and analysis [5].

(1) Infrastructure as a service layer (IAAS)
It realizes the resource virtualization of cloud and end, forms a unified resource pool, and allocates and schedules on demand. According to the access data volume, data access frequency and capacity requirements of distribution monitoring objects and sensors, as well as the demand of later business expansion, it has the elastic expansion ability of network, computing and storage.

(2) Platform as a service layer (PAAS)
It realizes the data standardization of distribution IOT, including data aggregation, data cleaning, data storage, data calculation, data processing and analysis, data mining and other functions. According to the requirements of numerous terminal units and rapid response, the functions of intelligent terminal management, unified data access and storage processing are realized in PAAS layer.

(3) Software as a service layer (IAAS)
It realizes the application service of distribution IOT, and provides a variety of micro services for actual business requirements, such as distribution station area monitoring, equipment status monitoring, asset management, distribution operation and maintenance, analysis and statistics.

The cloud master station in distribution station area is responsible for the whole life cycle management of intelligent terminal applications. In the application, based on the idea of Internet open source, the interconnection and interoperability of various business applications are brought into play to promote the rapid development of new formats.

3.3.2. Edge computing intelligent terminal. The intelligent terminal of distribution IOT needs to have three basic characteristics: hardware platform, software app and data standardization [6]. From the view of the architecture of the distribution IOT, intelligent terminals belong to "edge" equipment, and also have some characteristics of "end" equipment. In fact, some intelligent distribution and transformation terminals have become the integration of "edge" and "end".

By means of software definition, we can realize the deep decoupling of hardware resources and software application at the terminal side, respond to the changing application requirements of distribution station area without hardware change, and greatly expand the application scope of various terminal functions including intelligent distribution transformer terminal. At the same time, the level of edge computing is added at the terminal side to realize localized processing of sensing data, and the efficient collaborative mechanism between edge computing and cloud computing improves the overall computing capacity of distribution network.

4. System design
In the IOT, massive data and other scenarios, in order to meet the needs of wider connection, lower delay and better control, cloud computing is advancing to a more global distributed node combination, and edge computing has become a new antenna for cloud computing to expand to the edge side. Edge cloud collaboration is the collaboration between edge side and central cloud in most deployment and
application scenarios, including resource collaboration, application collaboration, data collaboration,
intelligent collaboration and so on. Edge cloud collaboration requires terminal devices or sensors to have
certain computing ability, which can conduct real-time processing of collected data, local optimal
control, automatic fault processing, load identification modeling, and interact the high-value data after
processing with the cloud. The cloud carries out security and risk analysis of the whole network, and
carries out pattern recognition of big data and artificial intelligence, and energy-saving strategy
improvement.

Combined with the architecture of the distribution IOT and based on the edge cloud collaboration
technology, the author designs an intelligent distribution management system based on edge cloud
collaboration, which is suitable for multi measurement and control scenarios of distribution network.

4.1. Intelligent distribution management system based on edge cloud collaboration
This paper proposes an intelligent distribution management system architecture based on edge cloud
collaborative computing, as shown in Figure 4. The architecture is based on the edge cloud collaborative
computing model, which mainly includes Edge-Cloud Operating System (ECOS) running on the cloud
and multiple ECOS edge fractal running on the edge side.

The basic principle of edge cloud collaborative computing uses edge cloud fractal technology,
integrated container cloud technology and multi-tenancy technology. By creating a fractal tenant on the
container cloud and subscribing to the micro service, the edge computing node can quickly copy and
generate an edge ECOS operating environment containing the specified intelligent distribution network
services. We call the edge fractal of ECOS, which is an important mechanism to realize the rapid sharing
and use of various services on the edge side of the intelligent distribution network.

![Diagram](image)
4.2. Cloud functional components of intelligent distribution management system

The cloud functional components of intelligent distribution management system mainly include four subsystems: data intelligent service, data management service, big data analysis and AI engine, and resource library. The specific functional components of each subsystem are shown in Figure 5.

![Cloud functional components of intelligent distribution management system](image)

Figure 5. Cloud functional components of intelligent distribution management system

4.2.1. Data intelligent service. Data intelligent service is the main means to realize adaptive evolution of intelligent distribution management system. The system includes data acquisition and interaction, data storage management, data analysis and processing, and data statistics display system, providing the ability of data life cycle processing. Among them, the data acquisition and interaction subsystem realizes the unified collection, cleaning and interaction of data through the standard data interface; the data storage management subsystem can provide structured and semi-structured data storage capacity according to the characteristics of data application, and support the storage of various types of data; the data analysis and processing subsystem can provide data processing functions, include data fusion, transformation, derivation and filtering, provide the modeling ability of data clustering and deep learning algorithm model to meet the adaptive evolution needs of the system; the data statistics display subsystem can provide convenient and reliable information display and visualization tools according to the needs of users at all levels.

Data intelligence services around the real-time business flow perception system, based on the data flow closed-loop to realize the data intelligence spiral rising closed-loop from state perception, real-time analysis, scientific decision-making and accurate execution, and finally realizes the adaptive evolution mechanism of the system based on data intelligence.

4.2.2. Data management service in intelligent distribution network. Data management services include data planning, data monitoring, simulation, life cycle and other aspects of distribution network business flow. Based on the actual distribution network business process, services are implemented as containerized micro services or micro applications, which can be easily deployed to the adaptive nodes. This component can realize the whole life cycle management of data. Distribution network planning is a work plan prepared by distribution network personnel before the specific implementation of
distribution network procedures in order to complete the distribution network business and achieve the expected distribution network objectives. Distribution network monitoring can analyze the actual state of each station area according to different space-time dimensions. Simulation deduction can carry out fault research and judgment based on historical data, and support panoramic, full state and holographic management of distribution network business through the above functional modules of business flow process of intelligent distribution network.

4.2.3. Big data analysis and AI engine. Big data analysis and AI engine includes speech recognition services, optical character recognition (OCR) services, natural language processing (NLP) services, and deep learning. Speech recognition services can help people automatically record speech and generate text, so that improve the work efficiency. Through OCR service and NLP service, the staff can quickly extract all kinds of key information from a large number of accounts to assist in analysis and decision-making. Big data analysis and AI engine can quickly help staff find potential defects in distribution network through various data algorithms, such as abnormal equipment, electricity stealing behavior of users, etc. Finally, NLP service can also assist users to quickly generate distribution network maintenance plan and work report.

These services can be encapsulated as containerized service resources in the form of micro services or micro applications, and can be efficiently deployed to the machines where the edge fractal is needed.

4.2.4. Resource library in intelligent distribution network. The resource library in intelligent distribution network mainly includes the intelligent distribution network model library, distribution network knowledge library and distribution network algorithm library which need to be continuously accumulated in the cloud. It mainly stores the specification and feature library of various terminal equipment, as well as the knowledge and algorithm library of various intelligent terminals. As a kind of cloud resources, they can continuously and effectively improve the intelligent level of intelligent distribution management system. The adaptive learning of resource library can be realized by AI.

4.3. Edge fractal function component of intelligent distribution management system

The functional components contained in the edge fractal of intelligent distribution network are mainly related microservices and micro applications which are packaged by containers and copied from the cloud, but the edge cloud generally does not include the relevant content of cloud resource library.

4.4. Edge cloud collaborative workflow technology for intelligent distribution system

After the construction of the intelligent distribution management system based on the edge cloud collaborative computing architecture is completed, the user can use the laptop for work as the edge computing node of the intelligent distribution management system. Through the following operation process, the edge fractal construction process can be completed and the required work environment can be constructed.

(1) Create edge cloud tenant

Create a new tenant on ECOS console. When the edge fractal of intelligent distribution network is required to have complete cloud console management capability, the container cloud installation package can be downloaded to the local tenant for installation and operation.

(2) Hardware resource configuration of edge cloud

Enter the management console interface and specify the server resources for the tenant to run. At this time, as long as you select the user's laptop, enter the IP address and administrator account password, after security authentication, you can obtain the corresponding control authority.

(3) Edge fractal construction of intelligent distribution network

Enter the management console interface, select the intelligent distribution network service to be installed on the laptop, and click "deploy" after completion. The system will install the edge fractal automatically according to the selected functional components above, and the images required for the installation of each functional component will be downloaded from the image library.

According to the guiding ideology of "dynamic and static integration, on-demand creation", if the cloud has built a private image library, the execution efficiency will be faster. Through the above edge
cloud fractal process, the laptop immediately has an stand-alone edge fractal of intelligent distribution management system, which is almost the same as the cloud intelligent distribution management system container cloud, but the intelligent distribution grid service installed on demand is running in the edge fractal. In this way, all kinds of services in the system can be used offline.

5. Application
By using SDN technology, we can flexibly interconnect one or more regional distribution networks with distribution stations as the natural management unit, flexibly customize the network, build a regional level energy management platform, realize the energy coordination and complementarity among distribution networks in time and space, provide powerful cooperation and optimization means for regional distribution networks, and provide high quality power service for users include distributed generation, energy storage and friendly power consumption.

SGCC has organized 7 units including Beijing, Shandong and Jiangsu to carry out pilot application of distribution station area management under the IOT architecture. By the end of 2018, it has realized intelligent management of more than 5000 stations, upgraded fault research and judgment from minute level to second level, full scene monitoring, fast interconnection of low-voltage equipment, flexible expansion of cloud master station and local decision-making of edge computing. It improves the comprehensive control of distribution and transformation information, and promotes the application of distribution IOT technology. In the pilot process, through the extensive participation of multiple stakeholders, we will work together to build the distribution IOT ecosystem.

6. Summary and Prospect
In this paper, according to the business requirements of multi-measurement and control scenarios in distribution network, the characteristics of software defined network (SDN) is explored. It introduces the idea of SDN innovatively, and puts forward a multi-measurement and control scenario architecture of distribution IOT based on SDN. Making full use of SDN technology's advantages of flexibility, efficiency and programmability, the integration of traditional monitoring system and IOT platform can be realized, and the system architecture, functional components and collaborative interaction mechanism can be studied and analyzed. Through SDN architecture to monitor the status of distribution network terminals, the basic information of the underlying communication equipment can be obtained. It realizes the cloud based, flexible management and configuration of intelligent terminals, and supports millions of terminal equipment access and intelligent operation and maintenance management. Through the edge cloud collaborative mechanism, the development needs of distribution network in lean management, scientific decision-making, etc. are supported. Thus, it endows distribution network related industries with energy, and ultimately realizes the sustainable development of power industry upgrading and sharing.

Next, with the industrialization and scale promotion of distribution IOT, sensor technology, communication technology and cloud edge computing technology and other key technologies of the IOT are constantly updated, in order to adapt to the demand side response of distributed energy, energy storage, electric vehicles and large-scale grid connection of interactive energy facilities, in the future, the open characteristics of the IOT platform will be used to explore distribution IOT architecture and market model with the introduction of electricity market price mechanism, at the same time, promote the practical promotion and application iteration of relevant technical specifications of distribution IOT, and give full play to the platform value of "hub type, open type and sharing type".

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