Research on the Development Direction of Smart Substations Under the Background of Power Internet of things Technology

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Abstract: As a key support for smart grids, the smart substation has formed a mature technical solutions after long-term development. In recent years, the internet of things technology has been applied in the whole aspects of power system transmission and distribution. Based on the extensive data collection and fusion, it has improved the state awareness, intelligent decision-making, and asset management capabilities of the power system. With the application of the internet of things technology, the development direction and technical architecture changes of smart substations are important topics that need to be considered at present. Based on the analysis of the current substation development route, this paper studies the applicability of electric power internet of things technology in smart substations, and proposes a smart substation technology solution that combines traditional technology routes and internet of things technologies, wishing to provide some reference for the research of smart substations.

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1. Introduction
The smart grid construction is in the ascendant. As an important fulcrum supporting the energy flow, information flow and business flow of the grid, the level of intelligence directly affects the effectiveness of smart grid construction. Since the launch of the first batch of smart substation pilot work in 2009, China has experienced many smart substation pilot studies, achieved a series of innovative results, and also proposed a series of standards and specifications, which effectively supported the construction and operation of smart grids⁴. The smart substation has currently formed a relatively mature technical scheme⁵. Based on the application of the IEC61850 standard, the overall structure of the secondary system has been built, and an integrated monitoring system has been established. Advanced applications such as sequence controlling, smart alarms, and source-end maintenance have successively been applied. Modular construction technologies such as prefabricated construction, prefabricated optical cables and plug-and-play have also been promoted.

In recent years, the internet of things(IoT) technology has been widely used in the field of power, giving rise to the concept of the power IoT⁷⁸. Through the application of information sensing, advanced communication, big data analysis and other technologies, based on extensive state perception, and communication transmission capabilities, power IoT focuses on the realization of equipment status monitoring and two-way interaction of power consumption, and uses data integration to promote the smart decision-making and asset management of the power system. In the substation, the problems of independent monitoring data and insufficient status assessment function are solved,
the coverage level of equipment and environmental monitoring in the station is improved, and the IoT communication network is reconstructed\[^{9-10}\].

Smart substation is still in the process of development. On the one hand, it needs to solve the existing problems\[^{5-6}\]. On the other hand, it needs to adapt to the new situation of power system. Especially in the case of continuous promotion of power grid digitization and extensive application of IoT technology, it needs to further explore how to optimize and improve the technical route of smart substation. This paper analyzes the applicability of power IoT technology in smart substations, and puts forward a smart substation technical scheme combining the traditional technology route and power IoT technology, so as to provide reference for the next development and evolution of smart substations.

2. Technical architecture of smart substation

At present, the smart substations are pushed forward by solving existing problems and adapting to the development of the power grid. Including of five important elements, "intelligent equipment + modular construction + integrated system + smart operation and maintenance + smart control", The substation deeply excavates the data in the station, integrates system functions, optimizes the structure layout, and enhances the level of intelligence as the basic operation unit of the power grid.

The intelligent equipment improve the accuracy and reliability of advanced applications on the basis of in-station information, such as equipment status monitoring, smart maintenance, and remote operation, strengthening the operation and maintenance ability of the substation.

The integrated system refers to the improvement of the integration between different equipment on the basis of ensuring the reliability of equipment, to reduce the number of devices and systems, simplify the structure of substations, improve the level of information sharing, promote resource reuse, and cut down the cost of substation construction, operation and maintenance..

Modular construction brings out the rapid construction and of the substation and improves the general interchangeability of equipment. Regarding equipments and functions as independent units according to the same bay or similar functions, the modularization technology realizes standardization of the external connection mode and plug-and-play of each unit.

3. Applicability analysis of power IoT in substation

3.1 The architecture system of power IoT

The power IoT is a multi-dimensional monitoring system that relies on the sensor terminals and communication network to complete data collection, storage, analysis, management and other functions. It can achieve a more accurate perception of power grid operation state, more effective distribution of system resources, more reasonable development of power services, which can guarantee the power system safe, reliable, green and efficient operation.

In the current power system, the integrated dispatch control system and the metering automation system can be regarded as typical applications of the power IoT. The power IoT can be divided into a three-layer architecture of perception layer, network layer, and platform layer\[^{8}\].

As the basic link, the perception layer obtains all kinds of physical information required, including current, voltage, quantity of electricity, power, equipment status, ambient temperature and humidity, position of operation and maintenance personnel, etc. through sensing terminals, video monitoring, digital instruments and other different sensing devices. After standardizing the data format of this information, the data is uploaded in the form of a general information model protocol.

The network layer is in addition to the backbone network and access network based on traditional optical fiber, carrier, wireless public network and other transmission methods, and responds to the access needs of different terminals such as low frequency, wide coverage, small area, and large bandwidth. The network layer adopts NB-IOT, LoRa, trusted WiFi and other wireless sensor technologies to supplement the access network, adapts to the development of new services such as distributed energy regulation, demand side response, unmanned inspection, mobile operation, etc.. It
completes data transmission by unified communication protocol to achieve wide area coverage of the communication network, and improve backbone transmission capacity.

The platform layer collects, stores, analyzes, and manages data information in the IoT, provides data support for various advanced applications and external business systems, and builds public data analysis services. On the basis of standardized processing, it develops basic application services that meet the needs of power business, and is directly invoked by external systems to realize preliminary data analysis and processing. In addition, it is also responsible for the management support of the entire IoT system.

3.2 Applicability of IoT technology in smart substations

The power IoT provides a wider range of state awareness and more optimized data transmission. From the perspective of functional requirements and existing technical architecture, the application of power IoT technology is consistent with the current development direction of smart substations, and IoT technology will play an important role in the construction and operation of substations [10-11].

In terms of demand, the power IoT technology can help solve current problems. One is to meet the information collection needs of the site. It is necessary to expand the scope of equipment condition monitoring and realize personnel operation monitoring, relying on the deployment of a wider range of sensing terminals. The second is to solve the problem of redundant and cumbersome system configuration. The application of the IoT technology can collect the data of each system, avoid information islands, reduce the repeated construction of system functions, and optimize the system structure in the station; The third is to improve the operation and management capabilities of substations. The power IoT can provide more complete data support for advanced functions in the station, thereby improving the accuracy and reliability of primary equipment condition monitoring and secondary system protection functions, promoting the practical application of program control and source-side maintenance technology, and granting substations personnel management and control capabilities, to strengthen management of various production areas.

In terms of technical architecture, the power IoT is compatible with the current system structure of smart substations. The existing equipment online monitoring system, secondary system, auxiliary control system and other systems can all be regarded as a three-layer structure of "collection terminal-access network-station function center", which is the same as the perception layer and network layer of the power IoT (Access network) is consistent. Many existing sensing terminals in smart substations, such as transformers, equipment status sensors, and environmental detectors, can be used as the sensing layer of the power IoT; the communication network in the station is the access network in the network layer; the local implementation of equipment status judgment, Functions such as the protection, measurement and control of the secondary system can be regarded as advanced functions possessed by edge nodes in the power IoT system.

From the perspective of work content, the IoT technology reflects the universality of work on the site. The same as the IoT system, focusing on the three parties of equipment, personnel and systems, the work in the smart substation station is based on data, and the safe and stable operation of the substation is realized through the interaction of man-machine-things.

For primary equipment management, the IoT technology can promote data penetration and strengthen the data support for condition monitoring; for secondary services such as protection, control, and measurement, the IoT technology can further optimize the distribution of functions and data transmission in the station; for the operation and maintenance of the station, IoT technology can provide extensive terminal coverage, data edge processing and integrated system design capabilities to solve current operation and maintenance problems. However, in practical applications, it is also necessary to consider factors such as safety production partitions to reasonably promote technological improvements in each work.

3.3 Positioning of smart substation in power IoT

Under the application of power IoT, the system architecture of the power system is further optimized.
As the perception layer and network layer (access network) of the power IoT, the smart substation completes data perception and collection in the station, which is sent to the IoT platform by the station gateway.

![Fig. 1 Data flow of smart substations under the electric IoT](image)

However, due to the security requirements of the secondary system data, data such as protection, measurement and control, and PMU are uploaded to the existing SCADA system through the station-end remote machine and distributed to the data center. The equipment online monitoring data is uploaded to the IoT platform (safe II area) through the gateway (safe II area) through the dispatch data network, and then uploaded to the data center. The related data of the auxiliary control system and operation and maintenance system are uploaded to the IoT platform (safe III area) through the gateway (safe III area) through the integrated data network, and then distributed to the data center by the platform.

4. Technical scheme of smart substation

4.1 Smart primary equipment

Intelligent primary equipment has the characteristics of intelligent sensing, intelligent measurement and intelligent control, and can realize functions such as state measurement and intelligent control. The structure of the intelligent primary equipment continues the form of "equipment body + sensor + intelligent components". Sensors and transformers monitor the running status of the body. The intelligent component collects and sends the status information of the device, and accepts system commands. In order to support the enhancement of equipment status perception and management capabilities, primary equipment should broaden the scope of online monitoring and perception, and integrate and optimize the information processing functions on the equipment side.

On the one hand, the scope of online monitoring on primary equipment has been expanded. Traditional analog meters are replaced with digital meters. The transformer is equipped with sensors such as oil chromatography, partial discharge, and bushing monitoring. On the GIS, monitor sensors such as SF$_6$ characteristics, circuit breaker characteristics, partial discharge, switch stroke are configured. At the same time, the integrated design and manufacturing of sensors and equipment must be promoted.

On the other hand, the existing decentralized IEDs are integrated as one intelligent component, as the edge node of equipment monitoring. The integrated intelligent component collects, summarizes and analyzes the key data of each sensor, and executes the equipment information number, status alarm, and intelligent control functions. The integrated intelligent components also send analysis results and related data to the station gateway through the IoT communication network in the station, and accept the control commands of the system to support remote control and equipment management.
on the basis of electric operation.

### 4.2 Integrated secondary system

As the edge terminal of the power grid dispatching control system, the secondary system at the substation side needs to strengthen function integration and information sharing.

The protection, measurement and control, PMU, remote control and other secondary devices are fully integrated into the secondary system integration platform, to centralize the secondary system functions in the station to the station control layer. The structure of the secondary system is simplified into two layers: the station control layer and the process layer. The secondary system integration improves information sharing and equipment integration, promotes structural simplification and data resource sharing. Its structure is shown in the figure below:

![Architecture of secondary system](image)

**Fig. 2** Architecture of secondary system

The process layer equipment is mainly an integrated unit, which integrates the functions of an intelligent terminal and a merging unit. The integrated unit serves as the information interface between the primary and secondary systems, passing the equipment status and electrical quantities to the station control layer, and executes the control commands of the station control layer.

Station control equipment includes secondary system integration platform, clock system (GPS/Beidou), intelligent remote motor, etc. Based on a generalized hardware platform, the secondary system integration platform integrates protection, measurement and control, PMU, telecontrol and other station control layer and bay layer equipment in the form of advanced functions in the hardware platform.

On the platform, the system changes from separation to integration to promote internal information sharing. The platform externally acts as an edge device of the large power grid monitoring system, undertakes information exchange and executes external commands. The integrated information platform can use the virtual machine or container technology operating platform as the basis.

The communication network is based on the IEC61850 communication protocol. The secondary system integration platform and the process layer equipment are directly connected via optical fiber/cable. A high-speed process bus is deployed inside the platform to support high-speed communication between hardware with different functions. The communication network also supports the delay measurable technology or the IEC1588 standard to ensure accurate time synchronization.

### 4.3 Smart operation and maintenance

The operation and maintenance related systems have been reconstructed using the power IoT technology. The substation builds unified IoT network, and a smart gateway is used as the terminal access and edge computing node. The operation and maintenance system accesses the terminal data in
the station through a common communication protocol, and analyzes various information in real time. It also optimizes the functions of various terminals to realize intelligent patrol, intelligent operation and safety control.

In terms of terminal deployment, on the one hand, the terminals deployed in the station are sensors required for device status perception, including the terminals of the primary equipment online monitoring system and the digital meters on the equipment. On the other hand, it also includes various sensors in the auxiliary control system of the substation. In addition, it also covers smart wearables, cameras, smart access control, positioning base stations, and other sensing terminals that support the development of smart operation and maintenance. Each terminal uses a unified communication protocol to access the smart gateway on the station side as much as possible.

In terms of sensor networks, in accordance with the requirements of information security and transmission capabilities, the perception layer LAN is constructed with wired networks such as ETH, RS232, RS485, and wireless private networks such as LoRa, ZigBee, NB-IoT, and trusted WiFi. The primary equipment online monitoring system terminal and the auxiliary system terminal are connected to the network, and the network transmits sensor information and control commands issued by the intelligent gateway.

As an intermediate device between the perception layer and the network layer, the smart gateway accesses the information of each terminal through the perception layer network to complete device management and remote control. For IoT terminals that use non-standardized protocols, the smart gateway can also convert the protocol and transmit standardized data information. The smart gateway can also be used as the edge node of the intelligent operation and maintenance system, integrating the functions of each terminal system, localizing and temporarily storing, processing data in real time, monitoring the status of the equipment and the operation and maintenance behavior in the station, and simplifying the amount of data uploaded.

![Architecture of intelligent operation and maintenance system](image)

**Fig. 3** Architecture of intelligent operation and maintenance system

In the advanced applications of intelligent operation and maintenance, on the one hand, in order to promote efficient operation and maintenance, intelligent inspections are carried out, relying on monitoring terminals such as digital meters, online monitoring sensors, and cameras; On the other hand, programmed operations are required. On the basis of equipment status information, double confirmation of switch operation results is carried out to ensure the accuracy of operation process and results; In addition, improve the safety of the operation and maintenance process. Through the SCADA system and intelligent technologies such as image acquisition and recognition, behavior pattern recognition, etc., the qualification review, arrangement of safety measures, operation monitoring, risk warning and safety assistance functions covering the operation process and operation area are constructed to comprehensively control on-site operation and maintenance risks.
5. Conclusion
Many pilot projects have been carried out in domestic smart substations, and relatively mature technical solutions have been formed. However, in the construction of smart grids, smart substations still expose many shortcomings in terms of primary equipment, secondary systems, and operation and maintenance. Smart substations need to be continuously developed in accordance with the concept of "intelligence, integration, and modularization".

Power IoT technology can effectively support smart substations to solve current problems. Smart substations and power IoT technologies are harmonious in the technical architecture. In the entire power IoT system, smart substations can exist as the perception layer and the network layer (access network). Data perception and collection are completed in the station and sent to the IoT platform by the station-side gateway.

To this end, in the context of the application of power IoT technology, smart substations build advanced functions of intelligent operation and maintenance and intelligent control in accordance with the infrastructure of "intelligent equipment + integrated system + modular construction". The substation develops edge terminals in intelligent primary equipment, integrated secondary systems, and intelligent operation and maintenance systems, forming a typical technical solution, and providing a reference for the next development of intelligent substations.

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