IOP Conf. Series: Materials Science and Engineering **719** (2020) 012009 doi:10.1088/1757-899X/719/1/012009

Study of Internet of Things Technology Applied in Intelligent Substation Auxiliary System

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Abstract. In order to improve the linkage of related auxiliary systems in intelligent substation and realize the complete monitoring and control functions of the equipment in the station, this paper integrates the technologies of Internet of Things, edge computing and big data to establish an auxiliary system of IoT intelligent substation. The overall structure of the system is introduced in detail. The effective calculation and reduction of the computing task of a single edge node is achieved by the application function and the edge calculation algorithm of task balancing allocation and scheduling, effectively improving the immediacy and security of the intelligent substation auxiliary system of the Internet of Things. The construction of transportation inspection has certain guiding significance.

1. Introduction

With the expansion of the scale of the power grid, the number of substations has increased dramatically. In order to improve labor efficiency and rationally allocate human resources, the substation is generally implemented with unattended and centralized monitoring modes. In this mode, the safety issues in the substation are particularly prominent. In recent years, substation equipment has been destroyed, and theft has occurred from time to time, causing some power outages. Therefore, it is an urgent need to implement practical and feasible technical means to monitor the relevant auxiliary systems in the substation, so that the safety control and intelligent control of the unattended substation becomes an urgent need. With the development of intelligent technology, intelligent robot inspection has become a possibility to replace manual inspection, which greatly reduces manpower and provides assistance for the rational deployment of personnel. However, since the patrol route and the patrol time of the robot are relatively fixed, the patrol content and the corresponding control functions are relatively independent, and they are not combined with the related auxiliary control system, the complete monitoring and control functions in the station cannot be realized[1]-[3].

At present, there are many kinds of production auxiliary systems such as video monitoring system, robot inspection system, conventional auxiliary control system and security perimeter system in substation. Each system only realizes some basic functions such as data acquisition, equipment monitoring and auxiliary inspection. Various systems are relatively independent, and the application scenarios are incomplete. There is still room for improvement in advanced applications such as data sharing, information interaction, intelligent decision-making, and intelligent linkage. Therefore, series of substation intelligent IoT integrated application systems are urgently needed, and the advanced application and data analysis functions of “substation operation task-oriented” are realized by collecting multi-dimensional big data.

Therefore, this paper applies the Internet of Things technology to the substation auxiliary system, and builds a set of IoT intelligent substation auxiliary system with its own characteristics. Combined with related equipment or system on the measurement and control network platform, it realizes security fire monitoring, environmental monitoring, power monitoring and operation assistance, maintenance assistance, operation status monitoring, pre-alarm and other system integration application, linkage control, asset management and other functions, achieving intelligent substation safe operation and safe operation management, improving information level of the intelligent substation full station, and providing decision-making technical support for the grid safe operation.

2. System Architecture

The Internet of Things (IoT) is an intelligent sensing network that collects data information through intelligent sensing devices of objects and transmits them via the network. The data is transmitted to a designated information processing center for processing to realize information interaction between people and objects, objects and objects. The academic community defines the Internet of Things as a network that intelligently identifies, locates, tracks, monitors, and manages through information sensing devices such as radio frequency identification, infrared sensors, global positioning systems, laser scanners, etc., connectting any item to the Internet for information exchange and communication according to the agreed protocol.

The whole operation process of the Internet of Things can be called IoT technology. In this paper, the technology is applied to the intelligent substation auxiliary system, and an IoT intelligent substation auxiliary system is constructed by using the characteristics of the Internet of Things. The system integrates various Internet of Things applications such as video surveillance, online monitoring, security perimeter, fire monitoring, environmental monitoring, infrared imaging, inspection robots, etc. It also realizes vertical integration of information between various IoT applications, horizontal data penetration, and highly integrated services, achieving information sharing and data integration between business applications flexibly. Moreover, it uses big data analysis, intelligent algorithm, image recognition and other technologies to realize automatic reading of equipment meter, automatic identification of circuit breaker and disconnector switching status, intelligent analysis of abnormal alarm, automatic development of inspection task, etc. In the development of the substation auxiliary system, the B/S architecture is adopted to realize the remote transmission and access of data through the power private network, which satisfies the system requirements of the sub-plant level deployment, operation and maintenance master station and the company multi-level application.

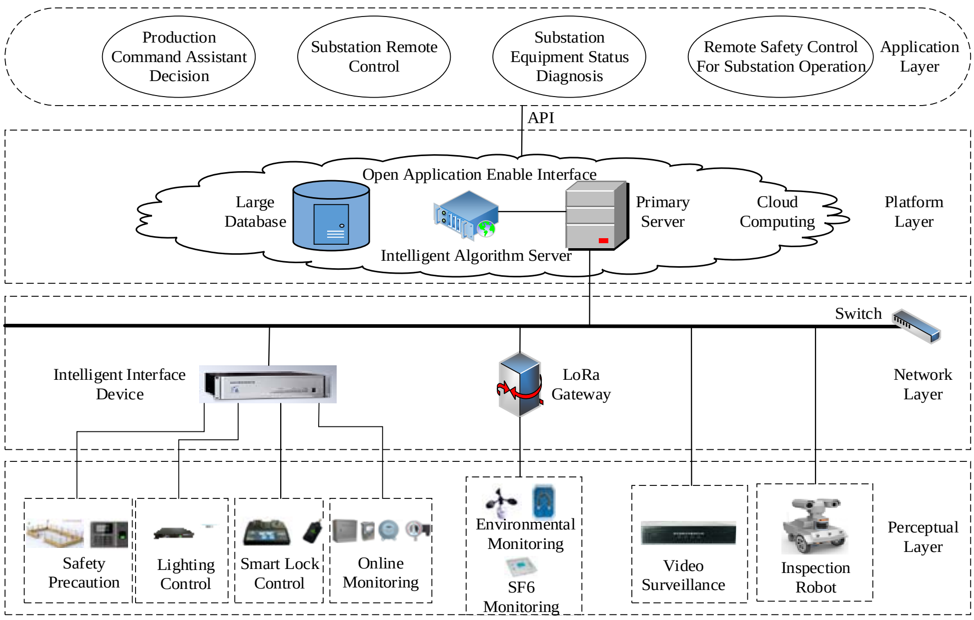

Figure 1. System overall structure

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The overall structure of the IoT intelligent substation auxiliary system is shown in Figure 1. Layered and distributed structure design is used to divide the system into sensing layer, network layer, platform layer and application layer. The subsystems at the bottom layer adopt independent networking and independent computing. The back-end system and the sensing layer device transmit data through the wired power private network, 1.8G wireless private network and LoRa wireless network. The system has terminal ubiquitous technical features such as access, platform open sharing, computing cloud edge collaboration, data-driven services, and application-on-demand customization. The whole system adopts the combination of central computing and edge computing to improve data processing efficiency and reduce the load of the system center server. Each subsystem and sensing device completes the front-end processing of various data collection, calculation, analysis, etc., to realize the edge of the data. The system background center server completes the integration, analysis and processing of panoramic big data, and realizes the data analysis at the center.

The communication protocol architecture of the intelligent substation auxiliary system of the Internet of Things is shown in Figure 2. The traditional substation auxiliary equipment such as fire protection, security, and light control in the Internet of Things system communicates with the Internet of Things system through the intelligent interface equipment through the DL/T 860 standard protocol. The Video surveillance equipment communicates with the Internet of Things system using standard national network B interface. The data of the inspection robot is transmitted through a dedicated SDK (Software Development Kit) protocol. The main transformer vibration and oil chromatographic monitoring data are processed by a dedicated server and communicated with the Internet of Things system using the IEC61850 protocol. The IoT system receives various types of telemetry, remote control, and remote signaling data of the substation station control layer SCADA (monitoring and data acquisition system)/human machine operator station through the forward isolation device to realize the real-time linkage and data analysis functions between the main devices and auxiliary devices, and provides the double criterion of circuit breaker and isolation switch position recognition for one-button remote sequence control.

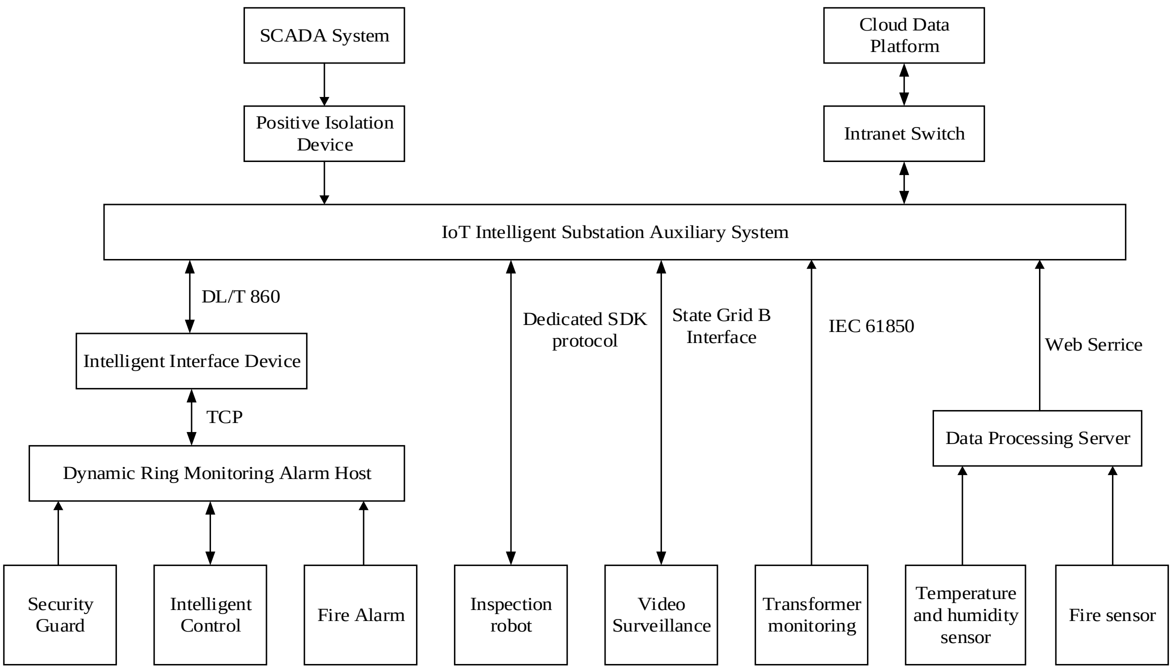

Figure 2. System communication protocol architecture

3. Edge Computing Application

With the rapid development of intelligent substations, the number of process layer devices and online monitoring systems are increasing day by day, and higher requirements are placed on the centralized data processing mode of intelligent substations. The previous data processing of the substation is based on the network cloud computing mode of the centralized core node. However, the cloud computing has the problem of real-time acquisition and analysis of the large number of inspection equipment data of the substation. For economic reasons, in order to prevent the centralized node from becoming a potential risk point and a factor to inhibit development, the system adopts the edge computing mode, and uses the edge node to acquire the sensing node at the edge of the network. The response of the data not only improves the response speed of the system, but also reduces the requirements of system transmission [4]. The specific design structure is shown in Figure 3.

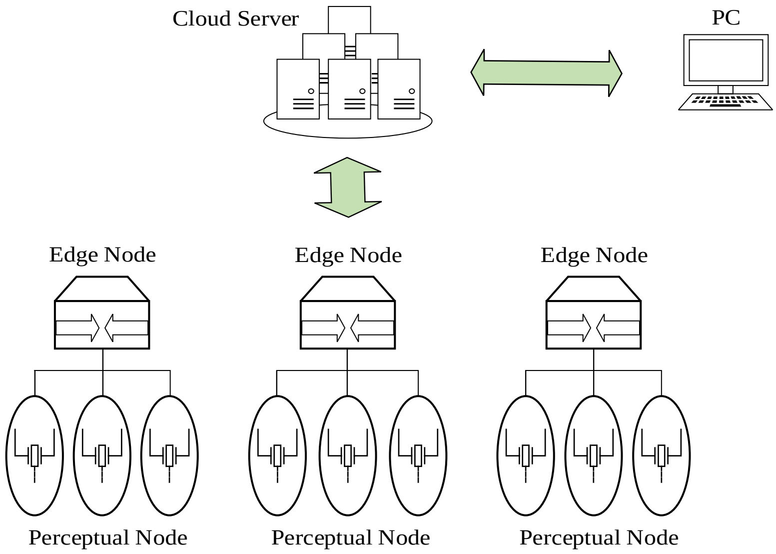

Figure 3. Edge computing architecture in the IoT environment

The edge calculation algorithm is oriented to the linear network structure of the IoT intelligent substation auxiliary system composed of multiple edge nodes. Each edge node simultaneously performs edge technology tasks and exchanges data with external devices, and then transmits the calculation to the cloud server. Therefore, in order to improve the overall network efficiency, it is necessary to balance the computational workload of each edge node with the network transmission calculation work to ensure collaborative processing between the edge nodes. In this paper, the edge calculation algorithm of task equilibrium allocation and scheduling is used to effectively control to reduce the computational task of a single edge node, and improve the real-time and security of the intelligent substation auxiliary system of the Internet of Things. The performance parameters between the cloud server and the edge nodes mainly include network traffic, delay, and response speed. During the execution of the edge computing task, the total delay of the transmission can be used to characterize the workload and working state of the edge node [5].

Assuming that the transmission rate between the edge node is expressed as S_i, the cloud server is u_i and the data volume of the cloud server transmission task is D_i, the transmission task transmission delay of the cloud server can be expressed as:

$$Tu_i = \frac{D_i}{u_i} \tag{1}$$

After the edge node S_i receives the task and the processing task rate p_i, the time for processing the assigned task can be expressed as:

$$Tp_i = \frac{D_i}{p_i} \tag{2}$$

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Assuming that the processing data of the j-th sensing node connected by the edge node S_i is D_{ij}, and the transmission rate is n_{ij}, the data time calculated by the edge node and uploaded by the sensing node can be described as:

$$Tn_{ij} = \frac{D_{ij}}{n_{ij}} \tag{3}$$

Therefore, the total delay of the edge computing task connected by edge node S_i to complete a cloud server with a data volume of D_i is:

$$T_{\text{delay}} = Tu_i + Tp_i + 2\max(Tn_{ij}) + \sum_j \frac{D_{ij}}{u_i} \tag{4}$$

The total delay T_{delay} can characterize the working delay of the edge node computing task load. Based on T_{delay}, the working state of the edge node is judged by the formula (5), and the corresponding adjustment is made.

$$\begin{cases} 0 < T_{\text{delay}} \le T_{\text{normal}} & \text{Normal working condition} \\ T_{\text{normal}} < T_{\text{delay}} \le T_{\text{overwork}} & \text{Busy working condition} \\ T_{\text{delay}} \ge T_{\text{overwork}} & \text{Fault working condition} \end{cases} \tag{5}$$

Among them, T_{normal} is the maximum normal working delay, and T_{overwork} is the maximum busy working delay. The corresponding state transition diagram is shown in Figure 4. According to this state transition diagram, the system performs edge calculation algorithm for edge node to perform task balancing allocation and scheduling. The corresponding edge calculation algorithm for different working states can make the edge node work more flexible and stable.

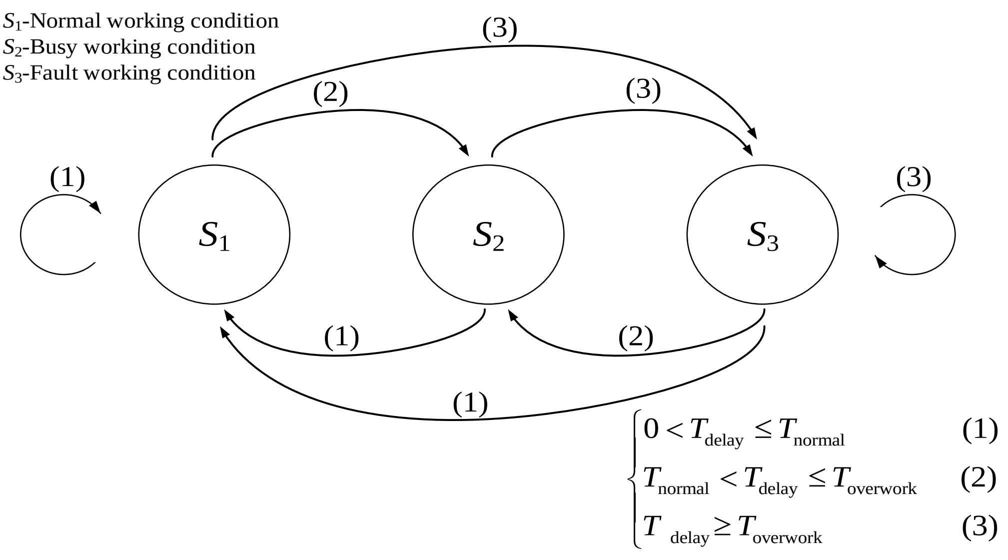

Figure 4. Edge calculation work state transition diagram

4. Application Function Design

The IoT intelligent substation auxiliary system based on edge computing is a basic management and information platform for people, machines and objects. It is the intermediate link of intelligent substation auxiliary system, which realizes the aggregation, calculation and distribution of energy information, as well as the control ability of equipment. Through unified technical standards, the system is oriented to the actual needs of operation and maintenance on energy flow, data flow, business flow and other elements. Other functions such as sharing data and services, supporting standardized access to all equipment status monitoring data of substations, and opening and closing functions for internal and external functions can be realized simultaneously [6]. The main functions are as follows:

(1) The intelligent inspection function.

The system mainly carries out daily inspections such as visual inspection, meter transcript, oil level monitoring, and location identification of circuit breakers, isolating switches, transformers, reactors, capacitors, etc., through video surveillance and data processes by substation monitoring equipments, inspection robots and so on. The system can automatically generate operation and maintenance inspection reports according to the requirements of substation operation and maintenance, for remote operation and judgment of operation and maintenance personnel.

(2) Comprehensive sensing of equipment status.

The system uses the main transformer online monitoring sensor, video monitoring, temperature and humidity sensor and other equipments to realize the full-scale self-real-time sensing of the substation power equipment status, and judge whether the data is normal according to the threshold and other criteria. When the device data is abnormal, all information of the device can be obtained in real time through the system. Moreover, the longitudinal analysis of the historical data, the phase comparison between the phase devices and the same type devices are performed, and the device state is initially diagnosed, thereby realizing the autonomous rapid sensing and early warning of the device state. For abnormal equipments, warning information is timely pushed to the operation personnel, the status monitoring strategy is timely adjusted, and data is uploaded to the platform layer for more accurate diagnosis and analysis.

(3) The equipment operation linkage.

The system and the substation station control layer SCADA system communicate through the forward isolation device. The SCADA system transmits the operation and alarm information of the primary device such as remote control, remote communication, and telemetry to the Internet of Things system through UDP (User Datagram Protocol) message format. When the device is operated once in the SCADA system, the IoT system server receives the corresponding UDP message and then intelligently links the video camera to access the corresponding video picture. When the SCADA system has important information such as SF6 alarm and protection trip, the IoT system automatically starts the corresponding inspection task to provide detailed inspection results for the operation and maintenance personnel.

5. Conclusions

This paper integrates Internet of Things, edge computing, big data and other technologies to establish an intelligent substation auxiliary system for the Internet of Things. The status of substation power equipment are comprehensively perceived and analyzed to increase mutual verification between data and reduce false alarms, and make the power equipment state perception accuracy higher. By applying the Internet of Things technology to the substation auxiliary system, intelligence and informatization of the substation operation management are realized. This method can ensure the stability of the substation management operation, improve the operation efficiency of the power grid to a certain extent, enhance the strength of the power grid, and lay a foundation for the strong operation of the power grid.

6. Acknowledgments

This work is supported by the Science and Technology Project of State Grid Corporation of China under Project of “Research on the third generation substation auxiliary system” with NO. 520530180015.

7. References

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