Edge Computing in Smart Hydropower Station: Cloud-Edge Collaborative Framework

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Abstract. With the deepening of energy revolution, smart hydropower station (SHS) has become the demand and inevitable direction of technological revolution and upgrading development of hydropower industry in China. Under the background of power Internet of Things and SHS, the massive sampled data perceived by intelligent terminals of SHS poses a major challenge to the traditional cloud computing centralized processing mode. As an important supplement to cloud computing, edge computing has received extensive attention from the power system. According to the complementarity between edge computing and cloud computing, this paper proposes a cloud-edge collaborative framework based on the introduction of SHS. Secondly, orienting the application in SHS, the key technologies of cloud-edge collaborative are discussed. Finally, the solutions based on cloud-edge collaborative for two typical application are discussed.

1. Introduction
With the deepening of energy revolution, the smart energy has become the development direction and goal of energy industry in China[1]-[2]. As an important part of energy system, the hydropower industry puts forward the development goal of smart hydropower station (SHS)[3]-[7]. Generally, SHS combines industrial Internet of Thing (IoT) platform and application centre, the former consists of sensor, actuator, embedded system, intelligent terminal and so on. IoT platform manages the terminals above and integrates multi source heterogeneous massive data generated by these terminals, while builds a unified data sharing platform for application centre. Based on data collected by IoT platform, the application centre provides various application for SHS, including production management, operations management, maintenance management, et al.

In the SHS, through the configuration of industrial IoT sensor devices and ubiquitous network interconnection, the heterogeneous industrial IoT of SHS can realize the comprehensive real-time perception and dynamic control of production operation. Among them, the distributed IoT devices at the edge of the SHS network collect real-time data, and upload the data to the application centre for processing and analysis. With the utilization of a large number of heterogeneous IoT devices in the SHS, the real-time heterogeneous data generated by them can reach GB or even TB level. Therefore, the data communication interaction between edge node and the application centre will become extremely frequent, which will lead to the IoT network congestion, response delay and other problems. At the same time, considering that most mobile IoT devices are powered by batteries or energy harvesters, frequent and inefficient communication interaction will generate additional energy consumption and reduce the
continuous working time of the above devices. Therefore, it is necessary to optimize and upgrade the current IoT architecture of SHS, and study the collaborative interaction mechanism among edge computing and cloud computing under the new architecture.

As a computing model suitable for large scale IoT applications, edge computing has been applied in smart city, smart building, smart medical, smart home and other fields[8]. Its basic idea is to deploy applications, services and content in the highly distributed IoT edge environment, and part of the computing tasks sink to the intelligent devices (such as smart phones, smart sensors, etc.) at the edge of IoT. The edge computing mode can meet the needs of services for low delay and high bandwidth, and avoid the network congestion caused by large scale and frequent data communication with cloud application centre, while reduce the computing pressure of cloud application centre.

According to the complementarity between edge computing and cloud computing, this paper firstly introduces the concept and progress of SHS, then proposes a cloud-edge collaborative framework. After that, the key technologies of cloud-edge collaborative towards application in SHS are discussed. Finally, two typical application scenes are introduced based on cloud-edge collaborative.

2. General structure of SHS

2.1. Definition of SHS
As defined in DL/T 1547-2016, the SHS adapts to the requirements of smart grid source and network coordination, and possess the features of information digitization, communication networking, integration standardization, integration of operation and management, business interaction, optimization of operation, and intelligent decision-making. The SHS uses smart electronic devices and smart equipment to automatically perform data sampling, condition measurement, operation control, protection, etc. In addition, the SHS can provide intelligent applications, such as economic operation based on the integrated platform, online analysis and evaluation decision support, safety protection multi-system linkage, etc., thus achieving safe and reliable production and operation, cost-effective and friendly interaction and green environmental protection goals.

2.2. Life-cycle Integrated Management and Control Platform
In order to construct SHS, the SHS life-cycle integrated management and control platform (S-limC) is developed by Power China Huadong Engineering Corporation Limited in [5]. The S-limC is composed of IoT and application centre, the former including two layers, i.e., infrastructure layer, edge computing layer. The application centre includes data layer, model and algorithm layer, service layer and application layer, as shown in figure 1. However, in this framework, most computing is performed in application centre, thus it’s need to introduce edge computing to reconstruct the SHS general framework.

![Figure 1. The architecture of S-limC in SHS.](image-url)
3. **Cloud-edge collaborative framework for SHS**

At this stage, the development of various intelligent applications in the SHS mainly has the following four characteristics and demands: 1) Terminal sensors are ubiquitously connected, and the data is diversified; 2) The value of the data in SHS has not been fully excavated; 3) Increasing business models make it hard to cope with the agile response of applications; 4) Data silos and business barriers are difficult to eliminate.

Cloud-edge collaborative is to realize the collaborative between edge computing and cloud computing, to dig and release the value of data. The cloud-edge collaborative method is mainly to upload the data to the edge node through the network after the terminal device generates a data or task request, and the edge node performs the computing task. In this stage, computing tasks with a large amount of calculation and high complexity will be migrated from the edge node upwards through the core network to the cloud application centre. After the cloud application centre completes big data analysis, the results and data will be stored in the cloud application centre. Based on the integrated data from edge nodes, the deep learning models can be trained and optimized. After that, the optimized output business rules and models are delivered to the edge node through the core network, then the edge node transmits the calculation results to the terminal device through the edge network, and the edge performs business execution optimization processing according to the new business rules issued by cloud application centre.

The capabilities and connotation of cloud-edge collaborative involve comprehensive collaboration at all levels of IaaS, PaaS, and SaaS, as can be seen in figure 2. Edge IaaS and cloud IaaS should be able to achieve resource synergy for networks, virtualized resources, security, etc. Edge PaaS and cloud PaaS should be able to achieve data synergy, intelligent synergy, management synergy, and business synergy. Edge SaaS and cloud SaaS should enable service synergy. Combined with specific application scenarios, the capabilities and connotations of edge-cloud collaboration will be different.

![Figure 2. The cloud-edge collaborative framework in SHS.](image)

Resource synergy: Edge nodes provide infrastructure resources such as computing, storage, network and virtualization, and have local resource scheduling and management capabilities. At the same time, they can collaborate with the cloud application centre to accept and execute cloud resource scheduling management strategies, including device management and resource management for edge nodes, and network connection management as well.
Data synergy: Edge nodes are mainly responsible for the collection of on-site data, perform preliminary data processing and analysis according to rules or data models, and upload processing results and related data to the cloud. The cloud application centre provides massive data storage, analysis and value mining. The overall capability and connotation of the edge-cloud collaboration is controllable and orderly flow between the edge and the cloud, forming a complete data flow path, and efficiently and low-cost data life-cycle management and value mining.

Intelligent synergy: Edge nodes are responsible for the inference of the deep learning model, and to realize distributed intelligence. The cloud application centre is responsible for the centralized training of the deep learning model, and then the trained model is delivered to the edge node.

Business synergy: Edge nodes provide modular, microservice-oriented applications, such as digital twins and networks. The cloud application centre mainly provides business orchestration capabilities to implement applications according to demand of SHS.

Management synergy: Edge nodes provide application deployment and operation environments, while manage and schedule the life-cycle of multiple applications at this node. The cloud application centre mainly provides application development and testing environments, and application life-cycle management capabilities.

Service synergy: Edge nodes implement some SaaS services in accordance with the cloud strategy, thus realizing customer-oriented on-demand SaaS services through the collaboration of edge SaaS and cloud SaaS. The cloud application centre mainly provides the service distribution strategy of SaaS services in the cloud and edge nodes, as well as the SaaS services undertaken by the cloud ability.

The biggest advantage of edge-cloud collaborative intelligence is to place data analysis on the edge for processing, avoiding the upload of massive data and greatly saving bandwidth costs. Cloud-edge collaborative intelligence technology efficiently implements various big data and artificial intelligence services and applications through collaborative optimization between the end, the edge, and the cloud. Cloud-edge collaborative intelligence realizes low-latency data processing by sinking computing power from the cloud to the data generation source, ensuring real-time data analysis. Cloud-edge collaborative intelligence ensures that the original data will not push to cloud, avoiding the risk of user privacy exposure, and providing a better privacy protection mechanism for sensitive data.

4. Key technologies of cloud-edge collaborative framework

4.1. 5G communication technology

As a new generation of cellular mobile communication technology, 5G plays a vital role in the process of network organization and information exchange, and is the foundation for the development of the future SHS. Compared with 4G and WIFI, 5G communication technology can provide edge computing network with huge network bandwidth, massive device access capability and ultra-high file transfer rate, which can accurately meet the requirements for low latency and high speed in industrial scenarios. In addition, in the current industrial production environment, due to the complexity of the industrial field environment and the unreliability of wireless networks, the locations of most terminal nodes are fixed, and the network connection is still mainly wired. The 5G network adopts the Control Plane/User Plane architecture, which can support smart terminals and sensors to be deployed more flexibly, thus to get rid of the shackles of traditional wired connections, and make industrial production and communication more convenient and efficient. For the above cloud-edge collaborative framework, 5G provides the end-to-end power private network with network slicing technology, thus to fulfil personalized network requirements.

4.2. Artificial intelligent technology

The integration of artificial intelligence and edge computing technology has endowed machines with the ability to "think" and "decide". In recent years, with the improvement of the computing power of smart devices, it has become possible to apply artificial intelligence technologies in edge computing networks. Among the many algorithms in the field of artificial intelligence, deep learning has achieved
the most outstanding effect in enhancing the performance of edge networks. Deep learning has powerful nonlinear representation capabilities. It can adapt to different industrial production environments by adjusting the number of neurons in the layer and the calculation rules between network layers to form different network structures. Convolutional neural network can be used to extract the implicit information in the image, and to realize the intelligent monitoring of the edge by integrating the advantages of low-latency edge computing. Reinforce learning learns the optimal task scheduling and resource allocation strategy through the interaction between the intelligence and the environment and so on. Long short term memory neural network is suitable for the time series data prediction, and can be used for the development of SHS equipment state trend prediction.

5. Typical application in SHS based on cloud-edge collaborative framework

5.1. Equipment health management based on cloud-edge collaborative

Based on cloud-edge collaborative framework, the multi-state monitoring system for electromechanical equipment is proposed in figure 3. The state monitoring data of equipment is acquired on the edge side and the data processing and analysis are performed on-site to realize the pre-processing and information fusion of edge sensing data. At the same time, the edge node cooperate with cloud application centre to achieve more advanced applications for operation and maintenance personnel and users, to achieve application goals such as operation and maintenance guidance, fault diagnosis and prediction, status warning, and management optimization of station equipment, and to improve the efficiency of operation and maintenance, reduce the risk of substation equipment failure, improve management quality and service application effects. The trained deep learning models are delivered to the edge node through the core network and the edge intelligent is perform in edge node with the delivered models.

5.2. Intelligent video surveillance based on cloud-edge collaborative

With the comprehensive transformation of the power system network, multiple cameras are installed in each SHS to monitor all corners of the station, so as to be able to grasp the situation of the SHS in real time and respond to emergencies in time. Therefore, the station stores a large amount of video image information. Combined with the daily work requirements of the SHS, how to make good use of these video image data has become an important content of the current station operation and maintenance management work, which is also a necessary automation project for the realization of unattended stations. At present, most of the solutions are based on the analysis and formulation of cloud intelligence, but too large amount of video to transmission, while there are a lot of invalid video information. Therefore, this will occupy and waste a large amount of network bandwidth resources and cannot be truly real-time monitoring and alarm. In order to cope with the above problems, the intelligent video surveillance based on cloud-edge collaborative is introduced, so as to fulfil the requirements of the automation and intelligence level of unattended stations.

The intelligent video surveillance system based on cloud-edge collaborative is shown in figure 4. In the system, two parts of work are carried out at the edge: 1) Intelligent video filtering, in this stage, a
large amount of useless video information is filtered; 2) Intelligent analysis and recognition, in this stage, the detection models is introduced to process valid videos in real time. The processing mode can be either pure edge-side inference, i.e., all video analysis is performed at the edge, or edge-cloud collaborative inference (model cascade), i.e., part of the video processing is performed at the edge, and then the processed intermediate results are sent to the cloud for further analysis. In the end, the analysis results (such as abnormal conditions) are returned to the user terminal and cloud application centre to trigger an early warning.

![Figure 4. Intelligent video surveillance based on cloud-edge collaborative in SHS.](image)

6. Conclusion
Toward SHS construction, a large number of heterogeneous IoT sensing devices are utilized in stations, and a large amount of real-time data is generated. It becomes a difficult problem to transmit and process the above-mentioned data efficiently. Cloud-edge collaborative is a new computing paradigm that combines the powerful resource capabilities of cloud computing with the ultra-low latency characteristics of edge computing to achieve the collaborative optimization goal of supporting cloud applications at the edge and cloud assisting edge localization requirements. This paper combines cloud computing and edge computing technology, using the high computing performance of cloud application centre and the limited computing power of IoT edge nodes, and proposes a cloud-edge collaborative framework for SHS. After that, the key technologies for cloud-edge collaborative are discussed. Finally, the paper gives two typical application scenarios based on cloud-edge collaborative framework in SHS.

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