

Design and Optimization of Digital Precision Operation and Maintenance System for Metering Box Based on Internet of Things

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Abstract: This article focuses on the design and optimization of digital precision operation and maintenance system of metering box based on IOT (Internet of things). Under the background of intelligent transformation of power system, the disadvantages of traditional metering box operation and maintenance mode are prominent. In order to achieve efficient operation and maintenance, this article designs the overall architecture of the system by using hierarchical architecture, covering the perception layer, network layer, platform layer and application layer, and carefully designs each functional module, and uses algorithms such as statistical analysis and evaluation model to deeply mine data. At the same time, this article puts forward optimization strategies for data processing speed, storage efficiency and communication stability, introduces measures such as distributed computing framework, hierarchical data storage and redundant communication links, and optimizes the operation and maintenance process. The results show that the data processing time is greatly shortened after optimization. In the tenth batch of data processing, the processing time is reduced from 80 seconds before optimization to about 30 seconds. The average time of fault handling is significantly reduced, taking the measurement error fault as an example, from 5 hours to 2 hours. This series of achievements effectively improve the system performance and operation and maintenance efficiency, and provide a scientific and efficient solution for the operation and maintenance of power system metering box.

1. Introduction

In today's era of rapid digital development, the process of intelligent transformation of power system is accelerating. As an important part of power system, the stable and efficient operation of metering box plays a key role in the accuracy and reliability of power supply [1]. The traditional operation and maintenance mode of metering box mainly relies on manual regular inspection and maintenance after failure, which is not only inefficient, but also difficult to find potential problems in time, and can no longer meet the high requirements of modern power system for operation and maintenance [2]. In this context, the digital precision operation and maintenance system of metering box based on IOT came into being, which has become an important direction of research and practice in power industry.

Judging from the research status, the application of IOT in the field of power equipment operation and maintenance started earlier in the world. Some developed countries have carried out a series of practical projects and achieved certain results. For example, the remote monitoring and diagnosis technology of metering equipment under the smart grid framework is relatively mature [3]. In recent years, the related research in China has also continued to heat up. Many scientific research institutions and power companies have actively explored and made a lot of progress in the integration of IOT technology and metering box operation and maintenance, but there is still much room for improvement in system integration, accuracy and optimization of operation and maintenance strategy [4-5].

This article aims to deeply study the design and optimization of digital precision operation and maintenance system of metering box based on IOT. By analyzing the application principle of IOT technology in the operation and maintenance scene of metering box, a set of efficient system architecture and functional modules are carefully designed, and feasible optimization strategies are

put forward for system performance and operation and maintenance process.

2. Related theoretical and technical basis

As an important part of the new generation of information technology, IOT realizes the interconnection between things and people through sensing devices, network transmission and intelligent processing. Its architecture usually includes perception layer, network layer and application layer [6]. The operation and maintenance of the metering box aims to ensure the stable and accurate operation of the metering box. Reliability theory is the key, which predicts the failure probability of equipment by evaluating the reliability index of each component of the metering box, so as to formulate maintenance strategies in advance and reduce the occurrence of failures [7]. Preventive maintenance theory emphasizes that measures should be taken in the incipient stage of failure according to the monitoring data of equipment operation state to avoid the expansion of failure and improve the efficiency and economy of operation and maintenance.

Data acquisition and transmission technology is the foundation of digital precision operation and maintenance, which ensures the rapid and accurate collection and transmission of sensory data [8]. Data mining and analysis technology extracts valuable information from massive operation and maintenance data, such as finding abnormal operation mode of metering box through cluster analysis [9]. Based on the results of data analysis, intelligent decision-making technology provides accurate decision support for operation and maintenance personnel with the help of expert system and machine learning algorithm, such as automatically generating the optimal maintenance scheme, which helps to realize digital and accurate operation and maintenance of metering boxes.

3. Design of digital precision operation and maintenance system for metering box

3.1. System overall architecture design

The digital precision operation and maintenance system of measuring box adopts hierarchical architecture design to realize efficient data processing and system functions. From bottom to top, it is divided into perception layer, network layer, platform layer and application layer.

The perception layer is mainly composed of various sensors, responsible for real-time collection of key data during the operation of the measuring box. For example, the temperature sensor monitors the temperature in the box to prevent the performance of the equipment from being affected by excessive temperature; The humidity sensor monitors the humidity to avoid equipment corrosion caused by excessive humidity; Current and voltage sensors obtain power parameters to judge whether the metering box is running normally. These sensors, like the "tentacles" of the system, keenly capture every operation detail of the metering box.

The network layer bears the responsibility of data transmission, using 4G/5G wireless networks, fiber optics and other communication methods to securely and quickly transmit the data collected by the sensing layer to the platform layer. This layer ensures the stability and accuracy of data in the transmission process, just like the "highway" of data, allowing information to flow unimpeded.

The platform layer is the core of data processing and analysis in the system. It receives data from the network layer and performs operations such as storage, cleaning and analysis. Through big data analysis technology, the hidden information behind the data is mined to provide decision support for the application layer.

The application layer provides intuitive and convenient operation interfaces for operation and maintenance personnel, realizing functions such as device management, fault warning, and operation and maintenance decision-making. Operation and maintenance personnel can grasp the running status of metering box in real time through this layer and handle abnormal situations in time.

3.2. Functional module design

The data acquisition module is responsible for controlling various sensors in the sensing layer to collect data regularly or in real-time, and performing preliminary preprocessing on the collected

data to ensure its accuracy and completeness.

The data transmission module is responsible for efficiently transmitting preprocessed data to the platform layer according to the communication protocol of the network layer. This module should have data encryption function to ensure the security of data transmission.

The data analysis module uses various data analysis algorithms to deeply mine the data stored in the platform layer. It is assumed that the evaluation model of measuring box operation state can be expressed by the following formula:

$$S = \alpha \times \frac{I - I_{\min}}{I_{\max} - I_{\min}} + \beta \times \frac{V - V_{\min}}{V_{\max} - V_{\min}} + \gamma \times \frac{T - T_{\min}}{T_{\max} - T_{\min}} + \delta \times \frac{H - H_{\min}}{H_{\max} - H_{\min}} \quad (1)$$

Among them, S is the comprehensive evaluation value of the operation state of the metering box, I is the real-time current value, and $I_{\min}$ and $I_{\max}$ are the minimum and maximum values of the normal current range respectively. V is the real-time voltage value, $V_{\min}$ and $V_{\max}$ are the minimum and maximum values of the normal voltage range respectively. T is the real-time temperature value, and $T_{\min}$ and $T_{\max}$ are the minimum and maximum values of the normal temperature range respectively. H is the real-time humidity value, and $H_{\min}$ and $H_{\max}$ are the minimum and maximum values in the normal humidity range respectively. α , β , γ and δ are the weight coefficients of each parameter, and:

$$\alpha + \beta + \gamma + \delta = 1 \quad (2)$$

When judging whether the metering box is about to fail, the failure probability prediction formula can be introduced:

$$P_f = \frac{1}{1 + e^{-(aS+b)}} \quad (3)$$

Among them, P_f is the failure probability of metering box, S is the comprehensive evaluation value of the above operation state, and a and b are the model parameters obtained by training historical data.

When evaluating the cost-effectiveness of the operation and maintenance scheme, the following formula can be used:

$$E = \frac{R}{C} \quad (4)$$

Among them, E is the cost-benefit ratio, R is the income (such as reduced power outage loss) brought by the normal operation of equipment after adopting an operation and maintenance scheme, and C is the implementation cost (including manpower and material resources) of the operation and maintenance scheme. The higher the value, the better the cost-effectiveness of the operation and maintenance scheme.

Table 1 lists the normal range of key parameters of different types of metering boxes in detail, which provides a basis for anomaly detection. Through long-term data accumulation and analysis, the evaluation model of metering box operation state can be constructed to predict the failure probability of equipment.

Table 1: Normal Fluctuation Range Table for Key Parameters of Metering Boxes

Metering Box Type	Voltage (V)	Current (A)	Temperature (°C)	Humidity (%)
Single-Phase Metering Box	210 - 230	0 - 100	-10 - 50	20 - 80
Three-Phase Metering Box	370 - 410	0 - 300	-10 - 50	20 - 80

Fault early warning module: based on the results of the data analysis module, when abnormal operation parameters of the metering box are found or possible faults are predicted, early warning information is sent to the operation and maintenance personnel in time. Early warning methods include SMS, APP push, etc., to ensure that the operation and maintenance personnel know the abnormal situation of the equipment at the first time.

Operation and maintenance decision-making module: according to fault early warning information and historical operation and maintenance data of equipment, intelligent algorithm is

used to provide optimal operation and maintenance scheme for operation and maintenance personnel.

3.3. Data flow design

The sensor in the sensing layer collects the data of the metering box in real time, and the data acquisition module preliminarily processes it, and then the data transmission module sends it to the platform layer through the network layer. The data storage unit of the platform layer receives data and stores it persistently, and the data analysis module obtains data from the storage unit for analysis. On the one hand, the analysis results are fed back to the data storage unit to update the equipment status information, on the other hand, they are transmitted to the fault early warning and operation and maintenance decision module of the application layer. The fault early warning module judges whether to trigger the early warning according to the analysis result, and if so, sends the early warning information to the operation and maintenance personnel. The operation and maintenance decision module generates an operation and maintenance scheme according to the early warning information and historical data, and provides it to the operation and maintenance personnel for execution. The whole data flow forms a closed loop, which ensures the continuous and efficient operation of the system and realizes the digital and accurate operation and maintenance of the metering box.

4. System optimization strategy and experimental test

4.1. System optimization strategy

In the actual operation, the digital precision operation and maintenance system of measuring box needs to be optimized in many aspects. In terms of data processing speed, with the increase of the number of sensors and the increase of data acquisition frequency, a large number of data flood into the system, which may lead to the delay of data analysis at the platform level. In terms of storage efficiency, the massive operation and maintenance data accumulated for a long time will occupy a lot of storage space and affect the overall performance of the system if it is not effectively managed. Communication stability is also the key, and the network layer needs to ensure that there is no packet loss and error code in the process of data transmission, so as not to affect the accuracy of operation and maintenance decision.

Aiming at the speed of data processing, a distributed computing framework is introduced, and the data analysis task is distributed to multiple computing nodes to process data in parallel and improve the processing efficiency. In terms of storage, the data layered storage strategy is adopted to store the hot data frequently accessed recently in high-performance storage devices, and the historical cold data is transferred to large-capacity and low-cost storage media to improve the storage utilization rate. In order to enhance communication stability, redundant communication link design is adopted. When the main communication link fails, the backup link automatically takes over the data transmission task.

The establishment of an intelligent work order system can effectively optimize the operation and maintenance process. When the fault early warning module sends out an early warning, the system automatically generates a work order containing fault details and recommended operation and maintenance scheme, and distributes it to the corresponding operation and maintenance personnel according to the emergency degree of the fault. The analysis of historical operation and maintenance records by operation and maintenance personnel can summarize experience and continuously improve the operation and maintenance knowledge base, thereby providing more accurate support for subsequent operation and maintenance decisions.

4.2. Experimental verification

In order to verify the effectiveness of the optimization strategy, relevant experiments were carried out. A certain number of measuring boxes are selected as samples in the experiment, and the performance indexes of the system before and after optimization are compared. The comparison of

data processing time before and after optimization is shown in Figure 1:

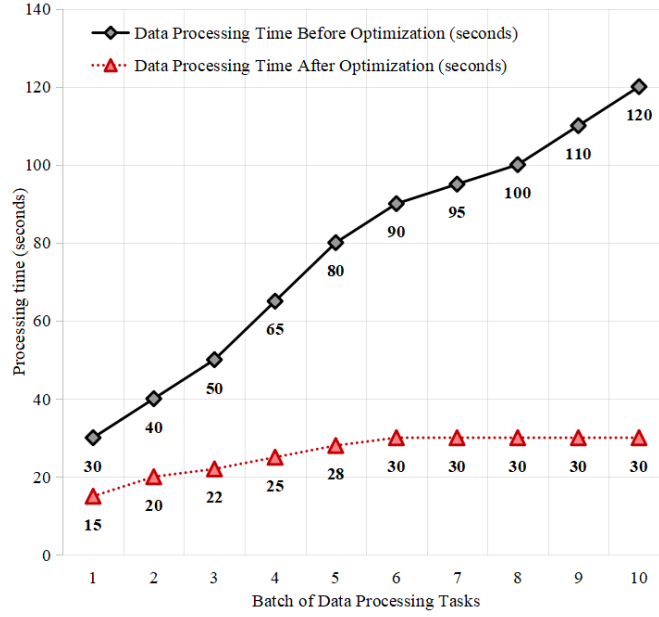


Figure 1 Comparison chart of data processing time before and after optimization

As can be seen from Figure 1, before optimization, with the increase of data volume, the processing time increased significantly, reaching 80 seconds in the fifth batch of data processing. After optimization, the data processing time is obviously shortened, and the processing time is stable at about 30 seconds even when the tenth batch of data is larger, which fully reflects the effect of the distributed computing framework on improving the data processing speed. The comparison of average fault handling time before and after optimization is shown in Figure 2:

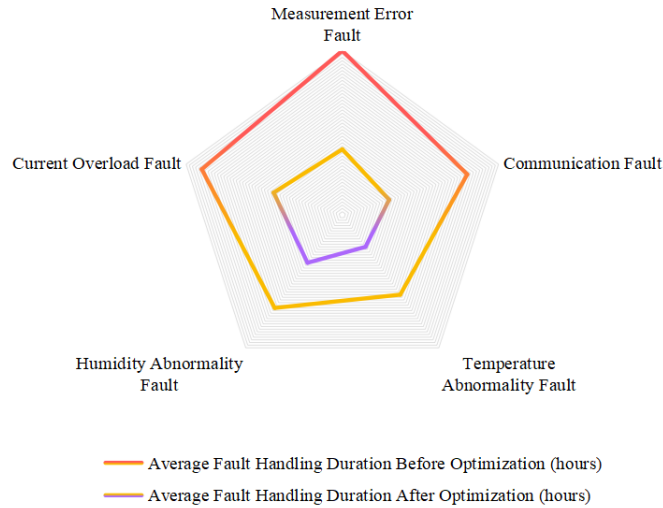


Figure 2 Comparison chart of average fault handling time before and after optimization

As can be seen from Figure 2, before optimization, the average time for handling all kinds of faults is long, for example, the average time for handling measurement errors is 5 hours. After optimization, through the improvement of intelligent work order system and operation and maintenance knowledge base, the average time of fault handling is greatly shortened, and the average time of measurement error fault handling is reduced to 2 hours, which shows that operation and maintenance process optimization plays a positive role in improving fault handling efficiency.

5. Conclusions

In this article, the design and optimization of digital precision operation and maintenance system of metering box based on IOT are deeply studied, and practical results are obtained. In the system

design, the hierarchical architecture realizes efficient data collection, transmission, processing and application, and all functional modules work closely together, from data collection and preprocessing to fault warning and operation and maintenance decision-making, forming a complete digital accurate operation and maintenance system. By designing the evaluation model of metering box operation state, failure probability prediction formula and cost-benefit evaluation formula, it provides quantitative basis for system operation state analysis and operation and maintenance decision. In terms of system optimization, a series of optimization measures based on IOT characteristics have achieved remarkable results. The introduction of distributed computing framework greatly improves the speed of data processing, the hierarchical storage strategy of data improves the storage efficiency, and redundant communication links enhance the communication stability. At the same time, the optimization of operation and maintenance process, with the help of the improvement of intelligent work order system and operation and maintenance knowledge base, significantly shortened the fault handling time.

The experimental data directly verify the effectiveness of the system optimization strategy. The significant reduction of data processing time and average fault handling time fully shows that the optimized system can deal with practical problems in the operation and maintenance of metering boxes more efficiently.

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