Construction and Application of Power Data Operation Monitoring Platform Based on Knowledge Map Reasoning

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ABSTRACT

Due to the gradual increase in daily power consumption by businesses and individuals, the power industry has seen an increased need to deploy more power equipment. This has led to a significant rise in the data generated by electrical equipment, a trend noted by the *International Journal of Emerging Electrical Power Systems*. In order to process, analyze, and manage such large amounts of data, it is necessary to introduce knowledge mapping technology into the power field. This technology allows the power data operation monitoring platform to obtain useful data from a large amount of information. In light of this phenomenon, based on an analysis of the requirements for platform construction and design principles, combined with the knowledge map reasoning method, this paper has effectively studied the construction of the power data operation monitoring platform and tested the performance of the experimental platform by assessing the response time of each functional module, data correctness verification, and data standard management.

KEYWORDS

Knowledge Graph, Monitoring Platform, Power Data Operation, Power System

INTRODUCTION

Under this background, the traditional power industry has changed. Various power data operation monitoring platforms are constantly put into production. These platforms can provide power equipment information for managers and are also responsible for displaying relevant data on the power system in different states. However, the traditional power data operation monitoring platform cannot meet the development requirements. The core of optimising the monitoring platform is to build a knowledge map and optimise and simulate the experimental environment. This knowledge map can accurately match, identify, and classify the target information in the database. The present study analyses the

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power system by building a knowledge map. It also ensures the safe operation of the power system by establishing a perfect power data processing platform, which has important practical value for the subsequent development of the power system.

Given the rapid development of power systems, many scholars have accelerated research on power system data platforms. Wang (2019) believed that the input of false data would seriously threaten the safe operation of a power system; thus, he comprehensively discussed the attack target, construction method, and consequences of false data. Hou (2019) proposed a data-driven method based on a power system to analyse the impact of renewable energy penetration on the power system. Ren and Yan (2019) proposed a fully data-driven power system security assessment method for the problem of incomplete data measurement. Koronen, Åhman, and Nilsson (2020) believed that the growth of the number of data centres would lead to an increase in power demand and the emergence of new power-intensive industries. Their analysis showed that demand response and the integration of energy systems promote the development of power market design. While the above studies have achieved good results, their methods are too traditional and not convincing enough (Liu, 2022).

Other scholars have different views about the research on power system data platforms. Mouassa, Tarek, and Ahmed (2017) analysed collected data through the Ant Lion Optimiser algorithm and solved the optimal reactive power dispatching problem of a large-scale power system. Pan, Teixeira, Cvetkovic, and Palensky (2018) performed a risk analysis on comprehensive data integrity and availability attacks of power system state estimation and proposed a security index for vulnerability assessment of such attacks. Liu's (2020) measurement data source authentication algorithm based on feature extraction technology automatically measured data and realised power system situation awareness. Netto and Mili (2018) estimated the rotor angle and speed of the synchronous generator based on the Kalman filter of robust generalised maximum likelihood Koopman operator, which was used to estimate the dynamic state of the power system. However, the above research on power system data platforms lacks in-depth analysis and discussion of knowledge map reasoning technology. Thus, the high integration and advantages of knowledge map reasoning technology and power system data platform are hindered (Man, Wang, & Liu, 2021).

In the present study, the construction of a power data operation monitoring platform is deeply examined with the knowledge map reasoning method. The experimental platform is also tested. The test results show that the maximum response time of each functional module is 4.5 s, and the minimum effect time is 1.6 s, which can meet the requirements of system performance. In the data correctness verification, the test results of the platform for index calculation, index maintenance, and index query and download are 93.12%, 96.43%, and 92.65% higher than the actual test values, whereas the testing accuracies of traditional experimental platforms are 87.26%, 84.17%, and 85.66%. In detecting the standard management of data, the efficiency indexes of the platform for data management of equipment type, equipment function, project classification, project progress, and project classification data management are 0.821, 0.845, 0.811, 0.843, and 0.862, respectively; the management efficiency indexes of the traditional experimental platform are 0.714, 0.693, 0.687, 0.711, and 0.724, respectively. This finding shows that the platform in this study is highly feasible.

DESIGN OF POWER DATA OPERATION MONITORING PLATFORM

Development and Demand Evaluation of Power Data Operation Monitoring Platform

According to research in the *International Journal of Emerging Electric Power Systems*, the daily management of power systems has become increasingly complex and the tasks of relevant staff have become increasingly onerous (Bie, 2017). The power system produces a large amount of data in the work process. Moreover, the staff needs to complete the collection, analysis, and statistical reporting of these data quickly. They must also summarise the data with other departments. The data integration in this process is complicated, easily causing data loss and tampering. Therefore, the power data operation monitoring platform must meet the management's needs (Remon, 2017; Colbertaldo, 2019).

The power data operation monitoring platform mainly monitors the power system operation in real time to ensure data integrity in the operation process. This monitoring platform can also provide timely warnings about the wrong data. Network management personnel can monitor and handle the network faults of the power system through the power data operation monitoring platform to provide services for the power system (Obaid, 2019).

The power data operation monitoring platform has achieved certain research results through continuous study and application by power researchers. Its changes are mainly divided into three stages. The development of the power data operation monitoring platform is shown in Figure 1.

System performance is the basis for the stable operation of a power data operation monitoring platform. The optimisation of system performance must be given attention during construction to meet the requirements of relevant performance (Wang & Sun, 2017). The performance requirements of the power data operation monitoring platform are shown in Figure 2.

The performance requirements of the power data operation monitoring platform are stability, reliability, operability, nonfragility, comprehensive coverage, and fault detection requirements.

Figure 1. Development of power data operation monitoring platform

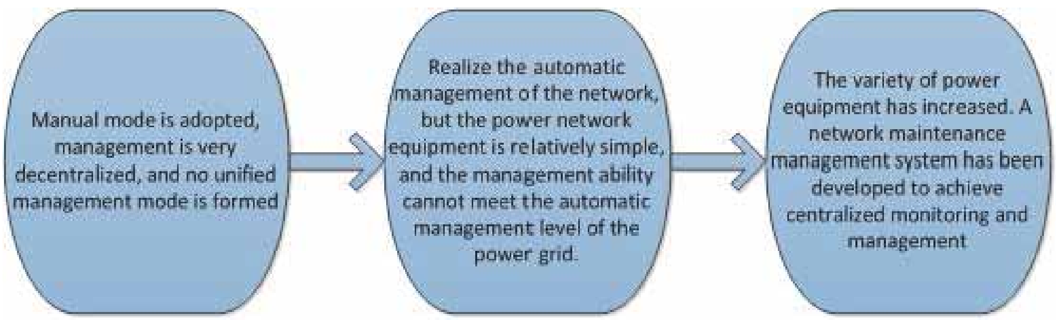


Figure 2. Performance requirements of power data operation monitoring platform

- **Stability Requirements:** The power data operation monitoring platform must achieve the real-time monitoring of power system data. Thus, the design must ensure that the platform can operate stably for a long time.
- **Reliability Requirements:** The normal operation of the power system is related to the normal development of real-life production. Thus, the design of the monitoring platform must be safe and reliable.
- **Ease of Operation Requirements:** The platform design must be simple and clear. Thus, relevant workers can quickly become familiar with the functional operation of the platform.
- **No Incomplete Requirements:** The platform can collect and process network data to prevent network failures.
- **Comprehensive Coverage Requirements:** The platform can cover all networks in the power system, integrate internal resources, achieve unified management, and quickly locate possible network failures.
- **Fault Detection Requirements:** When the network is abnormal, the platform can locate a fault through data analysis; moreover, it can quickly provide network maintenance measures (Babu & Mohan, 2017; Shi, 2017).

Design Principles of Power Data Operation Monitoring Platform

Using computer technology to build a power data operation monitoring platform is conducive to the monitoring management and data integration of power companies on network data, which are the main goal of power companies (Sharma, Suresh, & Saikat, 2017). In building the platform, the platform system must be built from functions, performance, security, and other aspects. The design process must meet the following principles:

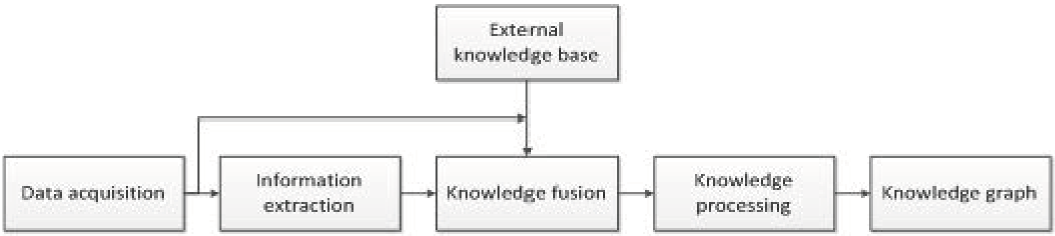
- **Progressiveness:** The power data operation monitoring platform is used to monitor the operation status of the power system in real time to ensure the stable operation of the power system. Therefore, advanced technologies are required in the design process to meet the current power data operation monitoring function (Heuberger, 2018).
- **Security:** The power data operation monitoring platform collects a large amount of data in the work process, such as information about equipment, potential safety hazards, equipment faults, and electric charges (Srinivasa, Sowmya, Shikhar, Utkarsha, & Singh, 2018). Thus, the management of data must be strengthened to prevent information leakage. Further, some important data shall be backed up and the operation methods of important functions of the system shall be saved to ensure comprehensive security (Arya & Narendra, 2017).
- **Practicability:** The power data operation monitoring platform affects the management of core businesses, such as equipment, performance, fault, and safety. The information that users pay attention to must be determined, and the practicability and operability of the platform must be improved based on the user's needs (Darvish, 2022).

Design Method of Power Data Operation Monitoring Platform

Knowledge Map Reasoning

The knowledge map combines the theories and methods of applied mathematics, graphics, information visualisation technology, information science, and other disciplines to achieve the goal of multidisciplinary integration. Based on the knowledge map, the reasoning identifies errors and infers new conclusions from existing data. The relationship between entities can be derived, and rich knowledge maps can be fed back through knowledge map reasoning; thus, advanced applications can be supported (Hogan, 2021; Paulheim, 2017). The overall framework for building a knowledge map is shown in Figure 3.

Figure 3. The overall framework for building a knowledge map



Given the continuous development of the power system, meeting the design of the power data operation monitoring platform by building a power knowledge map is very important because some knowledge in this field has changed and needs to be updated with the development of technology. The construction process of the power system knowledge map is shown in Figure 4.

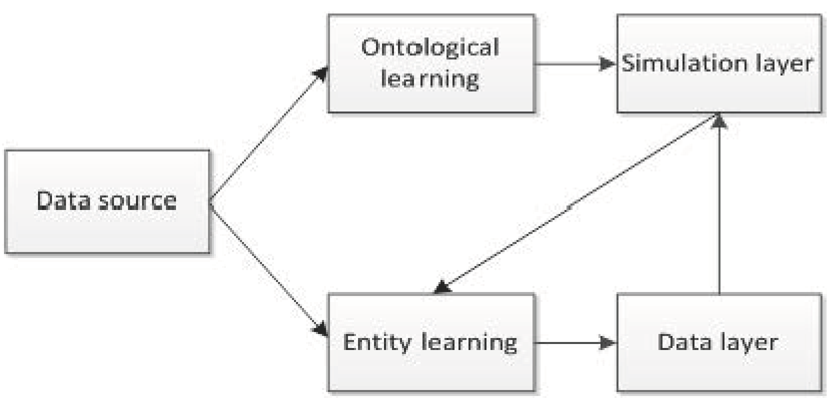
Knowledge Extraction Algorithm

The power data operation monitoring platform needs to analyse the data through the information in the power domain knowledge base to complete the real-time data monitoring. The traditional power domain knowledge base has a single source of knowledge acquisition. Moreover, the acquisition method is backward, leading to a high error rate of knowledge. Thus, the power system knowledge map must be intelligent through the knowledge extraction algorithm. The knowledge extraction algorithm can extract knowledge from many sources in the power field, thereby expanding the scale of the power system knowledge base. It is vital for the construction of the power data operation monitoring platform.

In the knowledge extraction algorithm, knowledge is a triplet composed of recorded entity, relationship, and entity set. Amongst them, the recorded entity is e ; the relationship is r ; the entity set is E . For any entity $e \in E$, a concept set $C\left(e\right)$ exists. All concept sets are calculated to generate all concept pair sets $C\left(e\right) \times C\left(e\right)$:

$$C\left(e\right) \times C\left(e\right) = \begin{pmatrix} \left(c_1, c_1\right) & \cdots & \left(c_1, c_n\right) \\ \vdots & \ddots & \vdots \\ \left(c_n, c_1\right) & \cdots & \left(c_n, c_n\right) \end{pmatrix} \tag{1}$$

Figure 4. Construction process of power system knowledge map



In the triplet, the entity on the left of the defined relationship is e_l, the entity on the right is e_r, and all relationships r are retrieved. Then, the relationship set is

$$R = \begin{pmatrix} \\ \left(e_{l1}, e_{r1}\right) \\ \left(e_{l2}, e_{r2}\right) \\ \vdots \\ \left(e_{\ln}, e_{rn}\right) \end{pmatrix} \tag{2}$$

If the instance set of relationship r consisting of entity pairs is defined as E_r, then

$$E_r = \left\{ e_l, e_r \middle| e_l, r, e_r \in N \right\} \tag{3}$$

Amongst them, e_l, r, e_r represents each piece of knowledge and N represents a knowledge set. When concept pairs are initialised, each pair of $e_i, e_j \in E_r$ must be traversed, the weight of e_i, e_j pairs of different concepts c_i, c_j must be calculated through typical function $f\left(c_i, c_j, e_i, e_j\right)$, and the final cumulative weight value must be obtained:

$$F\left(c_i, c_j\right) = \sum\nolimits_{e_l, e_r \in E_r} f\left(c_i, c_j, e_i, e_j\right) \tag{4}$$

Different methods produce different results because many choices for typical functions exist. In general, typical functions are expressed in two forms: from the perspective of average accumulation and from the perspective of frequency accumulation.

The typical function from the perspective of average accumulation is

$$f\left(c_i, c_j, e_i, e_j\right) = \begin{cases} 1, \ c_i \in c\left(e_l\right) \wedge c_j \in c\left(e_r\right) \\ \qquad 0, otherwise \end{cases}. \tag{5}$$

In this definition, each concept pair generated by a pair of entities is considered equal. Its typical implementation depends on the sum of E_r. Thus, the cumulative result is affected by the size of E_r.

The typical function from the perspective of frequency accumulation is

$$f\left(c_i, c_j, e_i, e_j\right) = n\left(c_i, e_l\right) \times n\left(c_j, e_r\right) \tag{6}$$

In this perspective, $n\left(c, e\right)$ represents the number of occurrences of entity e and concept c in the conceptual system. This method is often used when the number of texts is small. The product of the two frequencies produces a great error when an entity and the corresponding concept pair in the instance set appear too many times, resulting in unreliable entity concept relationships. In this regard, the typical function can be improved by the frequency angle:

$$f\left(c_i, c_j, e_i, e_j\right) = p\left(c_i \mid e_i\right) \times p\left(c_j \mid e_j\right) \tag{7}$$

Amongst them,

$$p\left(c_i \mid e_i\right) = \frac{n\left(e_i, c_i\right)}{\sum_{\left(e_i, e_j\right)} n\left(e_i, c_j\right)} \tag{8}$$

$$p\left(c_j \mid e_j\right) = \frac{n\left(e_j, c_j\right)}{\sum_{\left(e_i, e_j\right)} n\left(e_j, c_i\right)} \tag{9}$$

The use of typical functions must be based on mutual information theory. The mutual information of two variables X and Y is

$$I\left(X, Y\right) = \sum_{y \in Y} \sum_{x \in X} p\left(x, y\right) \log\left(\frac{p\left(x, y\right)}{p\left(x\right) p\left(y\right)}\right) \tag{10}$$

Amongst them, $p\left(x, y\right)$ represents the joint probability distribution function of X and Y, and $p\left(x\right)$ and $p\left(y\right)$ represent the marginal probability density distribution function of X and Y, respectively. People can solve the problem in which the entities and concepts frequently appear by applying mutual information. People can also directly add the amount of information to reduce the complexity of the algorithm.

Given the above algorithm process, each concept pair can obtain a cumulative weight value, sort the concept pairs according to the cumulative weight value, and generate the corresponding concept pair set through the input relationship set.

Construction of Power Data Operation Monitoring Platform

A new power data operation monitoring platform is built through knowledge map reasoning. Its overall structure is shown in Figure 5.

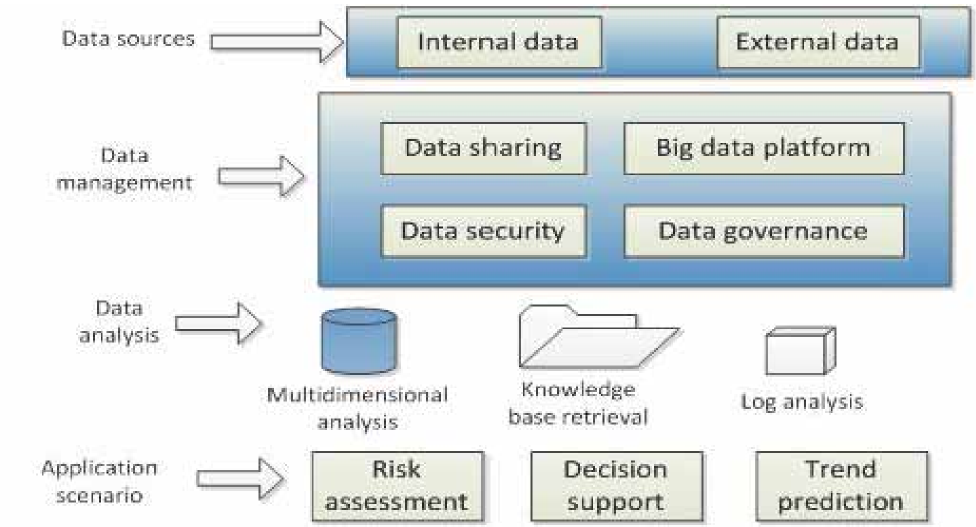
In the data collection layer, the power data operation monitoring platform is mainly divided into internal data and external data. Internal data refer to the data in the power system. They also refer to the data summarised by the enterprise based on previous experience. External data include public data and third-party data. The data management layer mainly realises data storage, completes data sharing, and ensures data security, thereby forming a safe and reliable database for the data. The data analysis layer checks the detected data through multidimensional analysis, full-text knowledge retrieval, and log analysis. It also provides alarms about erroneous data. The last layer is the analysis of application scenarios, including risk assessment, decision support, and trend prediction.

EXPERIMENTAL EVALUATION OF POWER DATA OPERATION MONITORING PLATFORM

Platform System Database Evaluation

Database design is the main part of the platform system design, realising the safe storage of data and documents. When designing the database required by the system platform, the main objects of the platform system and their corresponding main attributes must be analysed. Analysing the relationship

Figure 5. Power data operation monitoring platform



between objects is also necessary. On this basis, the corresponding physical table structure is designed, mainly including the equipment information table, user information table and security inspection information table of the power system.

Equipment Information Table

The equipment information table mainly stores the equipment information of the power system, including equipment number, equipment type, equipment status, and other information. The equipment information of the power system is shown in Table 1.

User Information Table

The user information table can manage the basic information of registered users and can be called at any time when it is used. It mainly stores the user's name, login account, password, and other information. The user information table is shown in Table 2.

Safety Inspection Information Sheet

When the data of the power system are analysed through the monitoring platform, timely inspection is required if data errors are found. Relevant contents must be recorded in the safety information checklist, including the inspection information ID, the name of the inspector, and the inspection object. The safety inspection information table is shown in Table 3.

Table 1. Equipment information

Field Name	Data Type	Field Length	Field Meaning
device_id	int	10	Equipment no.
equipment_type	varchar	16	Equipment type of the system
equipment_status	varchar	16	Working status of equipment
production_date	datetime	5	Production date of system equipment
effective_date	datetime	5	Effective date of system equipment

Table 2. User information table

Field Name	Data Type	Field Length	Field Meaning
uid	int	10	Name of the user
user_account	varchar	16	User login account
password	varchar	16	User login password
organisation	varchar	16	User's organisation
creation_time	datetime	5	Time of account creation

Table 3. Safety inspection information

Field Name	Data Type	Field Length	Field Meaning
check_id	int	10	Check information name
check_name	varchar	16	Name of inspector
check_object	varchar	16	Inspected equipment parts
status	varchar	16	Status of equipment at the time of inspection
check_time	datetime	5	Time of inspection

Platform System Detection

The responsiveness of the platform system must be tested to show the effect of the platform created in this study intuitively. The test environment is shown in Table 4.

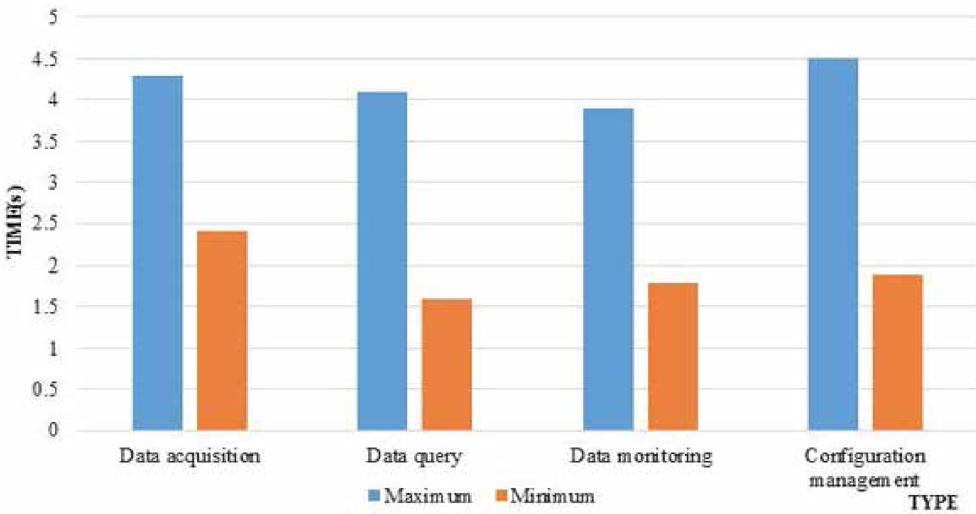
When the user operates the platform system through the client, the server processes the user's operation accordingly. The processing time is an indicator for judging the responsiveness of the platform system. The smaller the response time, the better the responsiveness of the platform system. Then, the response time of each functional module is analysed, as shown in Figure 6.

The platform in this study mainly serves the maintenance personnel and some management personnel of the enterprise-oriented power system. Thus, the number of people is not large. Therefore, the system supports 50 concurrent quantities. As shown in Figure 6, the maximum response time of the data acquisition function module is 4.3 s, and the minimum response time is 2.4 s. The maximum response time of the data query function module is 4.1 s, and the minimum response time is 1.6 s. The maximum response time of the data monitoring function module is 3.9 s, and the minimum response time is 1.8 s. The maximum response time of the configuration management function module is 4.5 s, and the minimum response time is 1.9 s. The maximum response time of each functional module is within 5 s, meeting the requirements of system performance.

Table 4. Experimental test environment

Attributes	Service	Environment
Software environment	Operating system	Windows Server 2008 R2
	Database server	MySQL
	Application server	Linux Red Hat 64
Hardware environment	Server side	CPU: Intel 2.6 GHz
	Client application	CPU: Intel 2.2 GHz

Figure 6. Response time of each functional module



Data Correctness Verification and Standard Management Comparison

The correctness of the platform monitoring data must be tested to verify the performance of the power data operation monitoring platform in this study and ensure the quality of the platform system. The experiment compares the test results of this platform with those of the traditional power data operation monitoring platform from the aspects of data correctness verification and data standard management to show the platform effect intuitively. The comparison results are discussed in the following sections.

Data Correctness Verification

Data correctness is verified from three aspects: indicator calculation, indicator maintenance, and indicator query and download. The results are shown in Figure 7.

The comparison of the data correctness verification results of the two platforms in Figure 7 shows that a certain gap between them exists. In Figure 7a, the test results of indicator calculation, indicator maintenance, and indicator query download are 93.12%, 96.43%, and 92.65% more accurate than the actual test values. The power data operation monitoring platform can obtain a comprehensive knowledge database under the knowledge map reasoning. The unstable data are removed, and the robust data are retained by screening the knowledge data. High-precision data detection is also realised. Figure 7b shows that the test results of indicator calculation, indicator maintenance, and indicator query download are not as good as those of the platform in this study; the test accuracy is 87.26%, 84.17%, and 85.66%, respectively. The construction of a traditional power data operation monitoring platform often focuses on adding knowledge data whilst ignoring the screening and elimination of knowledge data.

Standard Management of Data

The standard management of data refers to the maintenance of data that needs to be standardised in the platform system, including equipment type, equipment function, project classification, and project progress and project classification data management. The efficiency of data management for the above five aspects is shown in Figure 8. The efficiency of data management for equipment type, equipment function, project classification, project progress and project classification is represented by 1–5.

In the power data operation monitoring platform, the platform must provide various data management services for different data management contents, providing practical guidance for the smooth operation of the platform system. In the comparison of the standard management efficiency

Figure 7. Data correctness verification: a) platform of this article, b) traditional platforms

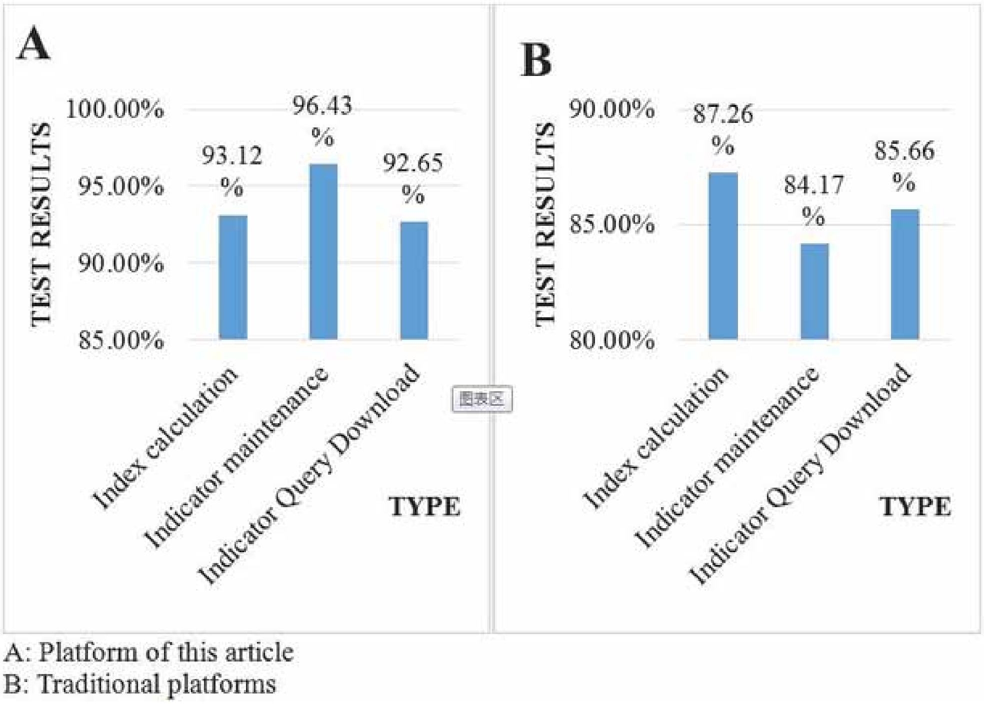
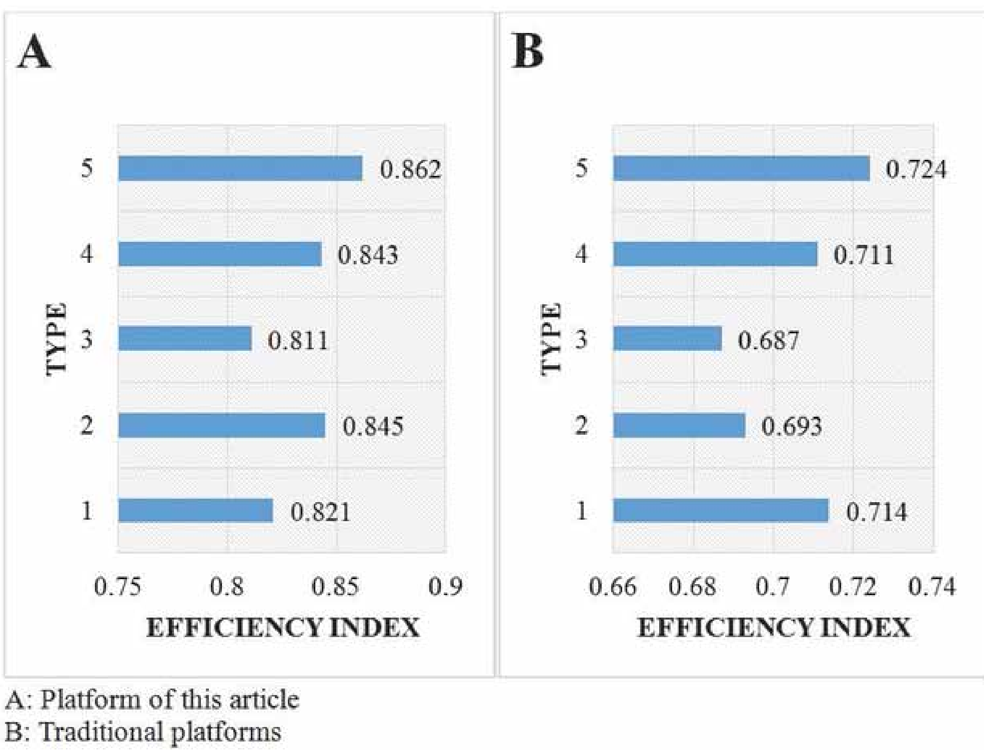


Figure 8. Standard management of data: a) platform of this article, b) traditional platforms



of data in Figure 8, the final data management efficiency of this platform is different from that of traditional platforms. Figure 8a shows that the efficiency indexes of data management for equipment type, equipment function, project classification, project progress, and project classification are 0.821, 0.845, 0.811, 0.843, and 0.862, respectively. In Figure 8b, the data management efficiency indexes of all aspects are 0.714, 0.693, 0.687, 0.711, and 0.724, respectively. In general, the data management efficiency of the platform reaches the standard when the data management efficiency index reaches above 0.6. However, the data management efficiency index of the two platforms indicates that the data management of the platform in this study is better than that of the traditional power data operation monitoring platform.

CONCLUSION

According to research in the *International Journal of Emerging Electric Power Systems*, the application of a power data operation monitoring platform in the power industry market is still in its initial stage. Although science and technology brought convenience and innovation to the construction process of the platform, they also increased the construction difficulty. Based on knowledge map reasoning, this study constructed a new power data operation monitoring platform according to the requirements and design principles of the power data operation monitoring platform. The response time of this monitoring platform not only met the requirements but also showed good accuracy detection and management efficiency in data correctness verification and data standard management. Thus, this monitoring platform can promote the smooth construction of the electric power data operation monitoring platform experiment and provide scientific data and information for the operation of the existing electric power system. It also possesses good operability. Although the performance and function of the platform have been significantly improved under the knowledge map reasoning technology, the present study still needs further improvement through follow-up research. In the follow-up research, people will meet diversified development needs through the continuous improvement of science and technology. The stability and practical value of the experimental platform will also be improved from different aspects.

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