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Design of Smart Grid System Based on IBA Architecture

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Abstract. To process the difficulty of equipment operation and maintenance supervision caused by the large number and wide distribution of smart grid power equipment, an innovative architecture integrated IBA is proposed, which combines big data and AI technology in different dimensions of the architecture to achieve hierarchical intelligence as needed. We provided the design process and key modules of the power grid system based on the IBA architecture: firstly, we introduce human-machine data under the architecture and propose the concept of hierarchical cognition. Then, real-time data collection is performed through the Internet of Things, and further mining and analysis of the data is achieved using cloud platforms. By Spark clustering based on k-means to partition state data, we establish corresponding Bayesian causal network models, and achieve data-driven modeling of smart grid equipment monitoring and operation. Finally, an application case of artificial intelligence is used to demonstrate the feasibility and effectiveness of the system. The experimental results demonstrate that the IBA fusion technology architecture has expanded the application scope of the IoTs in smart grids, and improved the intelligent level of smart grid construction and management.

Keywords. smart grid system; IBA architecture; IoTs; big data; AI

1. Introduction

With the continuous acceleration of the construction of the power system, communication networks have made significant progress in terms of capacity, structure, coverage, carrying capacity, overall scale, reliability, and intelligence. Communication is not only an important technical support for traditional power grid safety production and enterprise management, but also the foundation for realizing automation, informatization, and interactivity in smart grids. The importance of communication is becoming increasingly prominent, which puts forward higher requirements for security risk management of communication networks, control capabilities of large-scale communication networks, and disaster recovery capabilities of management systems. The smart grid has become a new trend and direction in the development of the world's power grid [1]. The main characteristics of smart grids are informatization, automation, and interactivity, requiring a strong information and communication support system. Therefore, forward-looking research and system design of smart grid communication management systems are particularly urgent and important. Relying on the smart power station cluster management system and utilizing the Internet of Things technology to connect various power stations for group management, the power station operation unit can scientifically and effectively control various businesses such as human, financial, material, supply, production, and sales of the power station cluster, achieving

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comprehensive control of production and operation. Simultaneously using big data technology to manage all data, maximizing the mining of valuable information, providing decision-making basis for operators, and improving management quality [2]. In addition, the application of artificial intelligence technology in power and integrated energy systems will achieve the combination of intelligent sensing and physical states, data-driven and simulation models, and auxiliary decision-making and operation control, thereby effectively improving the ability to control complex systems, improving operational security and changing business service models, changing traditional energy utilization patterns, and promoting the energy revolution. By enabling grid edge technology, artificial intelligence is revolutionizing the smart grid. Grid edge technology refers to the ability to monitor and control the power grid in real-time, allowing for more accurate prediction and improved response time. Artificial intelligence can be used to identify energy usage patterns and predict future demand. This information can then be used to optimize the power grid, reduce energy waste, and improve reliability. From this, it can be seen that the Internet of Things, big data, and artificial intelligence interact and promote each other in smart systems, creating a virtuous cycle. A technology that integrates the three has also emerged.

The IBA fusion technology architecture is an extension and expansion of the IoT technology architecture, which essentially introduces human-machine data within the IoT architecture framework and integrates the comprehensive application of big data analysis technology and artificial intelligence technology. It is a product of the close integration of IoT, big data, and artificial intelligence. The IBA architecture has greatly expanded the application scope of the Internet of Things, big data, and artificial intelligence, while improving the application quality of the three, maximizing the value of data, and achieving the sublimation of data quantity to quality. The expansion and innovation of applications are the core of the IBA integration architecture and an effective driving force for the development of new industries, laying a solid foundation for achieving the intelligence of the Internet of Things and the interconnection of everything [3]. Under the IBA fusion technology architecture, by abstracting and integrating data, business, and technology, reusing services and support capabilities, a cross departmental, cross hierarchical, and cross domain mid level support is constructed to meet various personalized front-end business needs.

This article analyzes the main requirements for big data analysis in smart grids, and then proposes a concept of IBA fusion innovation. The data fusion technology in the IBA architecture can integrate and fuse data from different data sources, including sensor data, power load data, weather data, etc. Through data fusion and analysis, more comprehensive, accurate, and real-time power information can be obtained to support monitoring, prediction, and optimization of the power system. At the user interface layer: This layer provides an interface for users to interact with the smart grid system, which can be in the form of web interfaces, mobile applications, etc., allowing users to monitor the status of the power grid in real-time, view analysis results, and make operations and decisions. In different dimensions of the architecture, hierarchical intelligence is achieved as needed, architecture functions are flexibly configured, and security management is autonomous and controllable. The system testing and analysis results indicate that in smart grid applications, the IBA architecture can play an important role in providing more efficient, reliable, and sustainable power management and operation, comprehensively improving the safety management level of power equipment.

2. Related Work

2.1 The Application of Artificial Intelligence in Power Systems and Integrated Energy Systems

Artificial intelligence (AI) is one of the most disruptive scientific technologies currently, with strong processing capabilities in computational intelligence, perceptual intelligence, and cognitive intelligence. The application of artificial intelligence technology in power systems and integrated energy systems will change the traditional mode of energy utilization and promote further intelligence of the system. Artificial intelligence technology is an inevitable choice for the development of power grids and an important strategic support for the transformation and development of comprehensive energy. Figure 1 shows the relationship and system application requirements between the power system and comprehensive energy system, big data, and artificial intelligence.

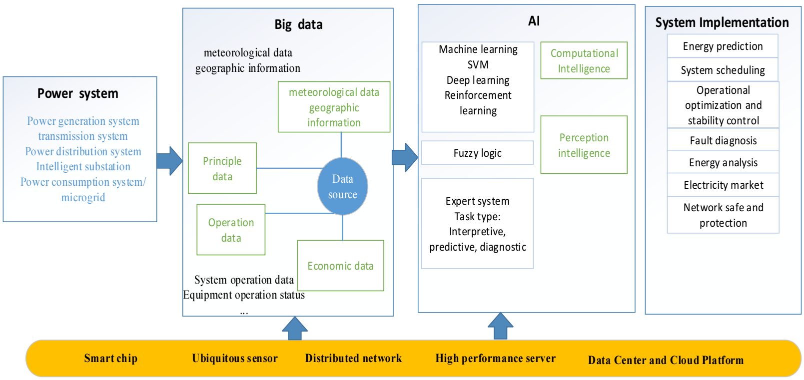

Figure 1. Relationship among power system, big data and AI.

In the context of the evolution of the power grid towards the energy internet and the development of the wide area interconnection of high voltage large power grids, the deep integration of artificial intelligence with power systems and integrated energy systems will gradually achieve the combination of intelligent sensing and physical states, data-driven and simulation models, and auxiliary decision-making and operational control, thereby effectively improving the ability to control complex systems and improving the safety and economy of energy system operation [4].

2.2. The Path to Implement IBA Fusion Applications

After collecting the state of the target object, data containing multiple types of sensors that may affect its state, and data formed by the observation of factual information on the human-machine interface on the end side, it can be uploaded northward to the gateway, distributed server, or big data platform according to the needs of the scene. According to the concept of multi-dimensional intelligence, micro closed-loop intelligent control can also be achieved in the front end [5,6].

(1) Layer the target data from south to north for data fusion, and perform control type data remixing at the edge cognitive layer as needed, scheduling type data remixing

at the distributed server layer, and decision type data remixing at the big data platform layer. The specific working principle is: at the edge cognitive layer, first select the data fusion node according to the needs of the scene by combining the output data of different sensors, establish a multi-source database, and use the elastic routing technology to establish the routing loop data through the routing protocol, through the east-west data flow. By using self operation and self reading technology to extract feature association data as needed, data governance is carried out to achieve data consistency description, and then control type data remixing is implemented, or data analysis sets are established. Relevant algorithms are used to achieve more efficient control and intelligent applications at the edge layer.

(2) In the distributed service cognition layer, the northbound data of the edge cognition layer or perception layer is stored according to the system corresponding, and then associated links are established for various specialized data application platforms with the goal of generating decision intelligence. According to the needs of intelligent decision-making, relevant data is extracted from the database, and its consistency is transformed and governed, and an analysis dataset that meets the needs of the application scenario is constructed. Such dataset has elastic reconstruction function, which can be combined and remixed with changes in the data source;

(3) At the cognitive level of big data platforms, collecting and organizing data: IBA fusion applications require a large amount of data support, so it is necessary to collect and organize relevant data, including structured data (such as data in databases) and unstructured data (such as text, images, etc.). Re-integrate various comprehensive data, including IoT perception domain data, edge cognitive domain aggregation analysis and calculation derived data, distributed cognitive domain aggregation and analysis derived data that can be used for prediction and decision-making, organizational data of relevant government organizations, ERP and CRM data of relevant enterprises, and consumption data of relevant individuals that can have an impact on the target state and can be used for prediction and decision-making. Through research on the data Understand, transform, clean, and follow certain rules for remixing and combining, establish an analytical dataset, and comprehensively apply multiple disciplines such as probability statistics, Data Mining Algorithms, fuzzy mathematics, neural networks, decision trees, RapidMiner, etc., to achieve scientific prediction and decision-making

(4) Choosing the appropriate fusion algorithm: IBA fusion applications require selecting the appropriate fusion algorithm to fuse data from different sources. Common fusion algorithms include weighted average method, model fusion method, Bayesian network, etc. Develop corresponding fusion applications or models based on the selected fusion algorithm. This may involve steps such as programming, modeling, and training, depending on the chosen technology and tool.

3. Design and Implementation of Smart Grid System Based on IBA Architecture

3.1 The Establishment of IBA Fusion Model

Under the IBA framework, the normalization of data collected by the Internet of Things refers to the unified standardized processing of data collected by different sensors or devices to ensure the comparability and consistency of data among different devices [7]. Choosing an appropriate normalization method depends on the characteristics of the data and the requirements of the application. When normalizing data, it is necessary to consider the distribution of the data, the handling of outliers, and the impact of normalization on subsequent analysis and decision-making. Under the IBA fusion structure, the edge side data aggregation layer, which connects the east-west data, is the key to achieving data vertical splitting and horizontal remixing. It can achieve comprehensive analysis and decision support for data from different edge devices and sensors. This helps to improve the availability, accuracy, and real-time of data, providing a better foundation for subsequent data fusion and applications. The distributed cognitive layer is a fusion application of higher-level big data and artificial intelligence, achieving deeper data mining analysis and artificial intelligence applications. The IBA fusion technology architecture, as shown in Figure 2, not only integrates the interconnection between things in traditional IoT architectures, but also incorporates a higher level of interconnection between "people" and "things". By combining artificial intelligence and machine learning technology, the system can learn and reason from a large amount of data, helping people make smarter decisions.

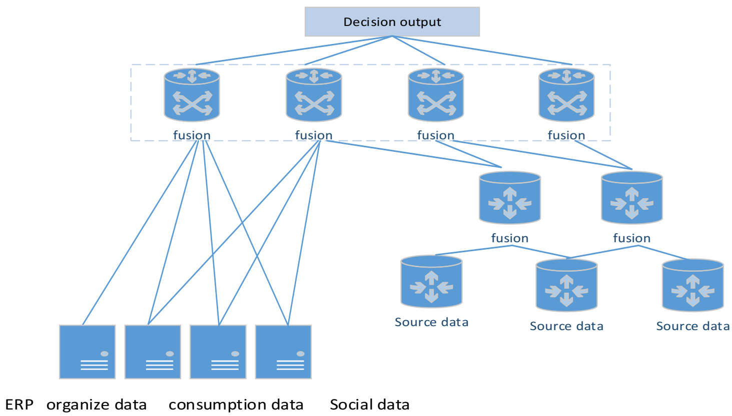

Figure 2. Distributed cognitive layer fusion model of IBA structure.

3.2 Smart Grid System Architecture

The smart grid system should achieve data collection, operation monitoring, accident recording and analysis, relay protection, etc. of the company's power supply and distribution system during operation through multi-functional power monitoring devices, communication networks, and computer software, to complete the safe power supply, electricity management, and operation management of the enterprise. The smart grid system based on IBA architecture should be composed of station control management layer, network communication layer, and on-site equipment layer. Its main functions include human-machine interface monitoring, which visually displays the operating status of distribution lines in the form of a distribution diagram. It can monitor the voltage, current, power, power factor, energy and other electrical parameter information of each circuit in real-time, dynamically monitor the closing and opening status of circuit breakers, isolation switches, grounding switches, and related faults of each distribution circuit alarm and other signals. By adopting a layered and modular technical architecture, the smart grid equipment monitoring big data platform relies on IoTs technology, cloud service platforms, and equipment business systems, mainly including data acquisition layer, data storage layer, network transmission layer, public service layer, and application service layer. Each layer adopts a unified service interface. This architecture can achieve independent development and maintenance of various functional modules, while also facilitating system expansion and upgrading. Such architecture design helps to improve the reliability, performance, and maintainability of the system, providing strong support for the monitoring and operation of the smart grid.

3.3 Key modules design

(1) Data acquisition based on IoT

After obtaining various types of data on the distribution network site through multi category collection terminals, they are transmitted to the cloud based main station platform through heterogeneous and integrated communication networks. The cloud based IoT master station of smart grids typically uses various technologies and tools to achieve data collection and cleaning. For example, devices such as sensor networks and IoT gateways can be used to collect data, and data storage and computing services provided by cloud platforms can be used for data cleaning and processing. Through data collection and cleaning, the cloud based IoT master station can obtain and process a large amount of IoT data in real-time, providing users with more accurate and reliable data support, and providing a data foundation for various application scenarios, such as smart homes, smart cities, industrial automation, etc.

(2) Real time batch processing technology for data

As the data of smart grid devices continues to increase, it is necessary to perform calculations and processing on batch device data. This article establishes a Spark cluster, including a main node and multiple work nodes. Then, the data is loaded into Spark's memory and can be manipulated and transformed using Spark's RDD or DataFrame data structures. Through parallel processing and distributed computing, large-scale data can be quickly processed in batches. In terms of real-time batch processing, Spark also provides Spark Streaming function, which can process data streams in real-time. By dividing the data stream into small batches and applying batch processing operations on each batch, real-time data processing and analysis can be achieved. Using Spark clustering based on k-means to partition state data, the collected data is divided into different types, reducing the scope of data inspection. Further use the Granger causality test method to conduct causal analysis on data sets with potential correlation relationships, and construct a data-based causal model. The analysis logic is shown in Figure 3.

(3) Decomposition and storage of fault information

Proper decomposition and storage of fault data is one of the key steps in achieving fault analysis, judgment, management, and display Fault information extraction involves extracting basic information from stored fault data, such as fault type, timestamp, location, etc. This can be achieved by querying the database or applying specific data processing algorithms. Based on the data structure of the data communication protocol, a data record type TZigBeeCom was designed to record the current fault data received for temporary storage, laying the foundation for the decomposition and storage of fault information. The data record structure is defined as follows:

```
Typedef struct{
```

Uint8_ T deviceID// Device ID
Uint16_ T faultCode// Fault codes
Uint32_ T timestamp// time stamp
Float voltage// voltage
Float current// current
}TZigBeeCom;

This data record type contains the following fields:

DeviceID: Device ID, represented by one byte (8 bits).

FaultCode: Fault code, represented by two bytes (16 bits).

Timestamp: A timestamp, represented by four bytes (32-bit), typically an integer representing time.

Voltage: Voltage, represented by a floating-point number of four bytes (32-bit).

Current: Current, represented by a floating-point number of four bytes (32-bit).

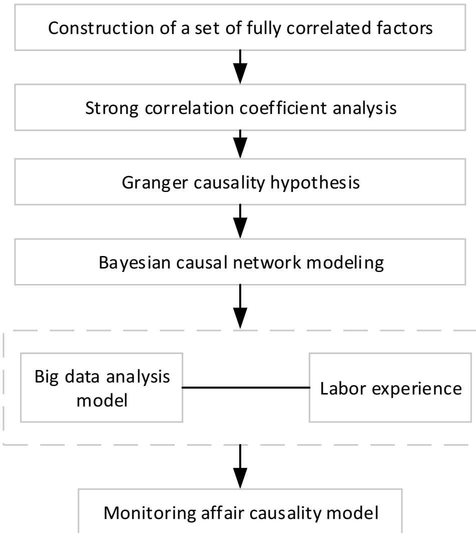

Figure 3. Big data causality analysis logic.

4. System Implementation and Testing Analysis

The smart grid can understand the current operating status of devices by monitoring their real-time performance. Through sensors and monitoring systems, smart grids can collect various data of devices, such as temperature, pressure, current, etc., and transmit these data to the central control center in real-time. By establishing a comprehensive monitoring system, timely detecting faults and taking corresponding measures, the reliability and efficiency of the power grid can be effectively improved. The central control center can analyze and process these data to understand the health status, operational efficiency, and possible malfunctions or anomalies of the equipment. In this way, the smart grid can take timely measures, such as repairing or replacing equipment, to ensure the stable operation and efficient performance of the grid. The smart grid management system interface includes real-time data of power load, voltage, current and other parameters, as depicted in figure 4. In this way, operators can always understand the operation of the power grid and take necessary measures in a timely manner; It can also analyze historical data of the power grid, provide data visualization and reporting functions, help users better understand the operation of the power grid and make corresponding decisions.

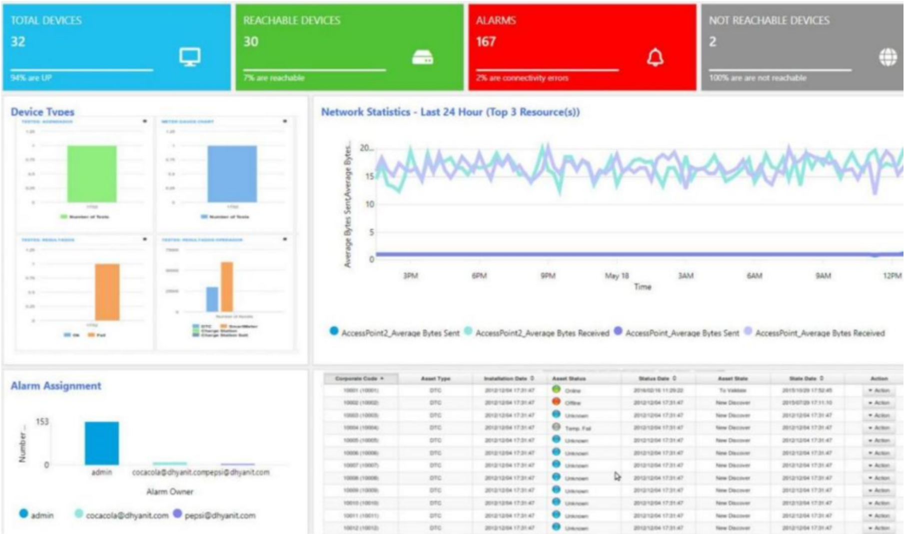

Figure 4. Smart grid management system interface.

After actual measurement, the system has reliable second level acquisition capability. For the method of analog data collection, in terms of energy consumption and electrical parameter data collection, ordinary electricity meters can be connected to the upper computer through RS485 communication, and then the data can be viewed by the upper computer. However, in the current prevalence of the Internet of Things, using wireless electricity meters or connecting to the gateway through 485 cable, and then uploading the data wirelessly to the system platform through the gateway is the most convenient, fast, and effective solution. The intelligent communication management machine of the system supports receiving commands issued by the superior master station system and forwarding them to the intelligent series units in the target area, completing remote control or device parameter tuning of the opening and closing of various switchgear in the plant, achieving remote control and adjustment functions, and achieving the goal of remote output scheduling commands. The system, combined with big data technology, can effectively analyze various structured and unstructured data, and on this basis, achieve the final detailed statistics and report generation of the power grid dataset. It interfaces with other systems and provides basic management functions such as adaptation, conversion, and storage for data and the basic steps include data preprocessing and data storage. Figure 5 provides the data management mode of smart electricity meters under IBA structure.In order to test the effectiveness of the power grid AI business support system based on IBA architecture proposed in this article, it was experimentally compared with traditional smart grid and opportunity data mining business support systems. Create a 3+1+1 product architecture in the cognitive layer, namely: Convergence gateway, edge computing gateway, collaborative gateway+ubiquitous Internet of Things access platform+multi-source heterogeneous data management platform. The system monitors the working status and power data of the customer's distribution system in real-time, saving costs and providing good operation and maintenance services for customers. The platform provides services such as overview, power data monitoring, power quality analysis, power analysis, daily/monthly/annual energy data reports, abnormal event alarm records, operating environment monitoring, and operation and maintenance orders. It supports multi-platform and multi-terminal data access and can achieve intelligent production information and management data. The test objective is to assess the success of the customer service support system. The comparison results of the completion rate of system business are shown in Figure 6. The design system business completion rate of IBA technology architecture is higher than that of two traditional systems.

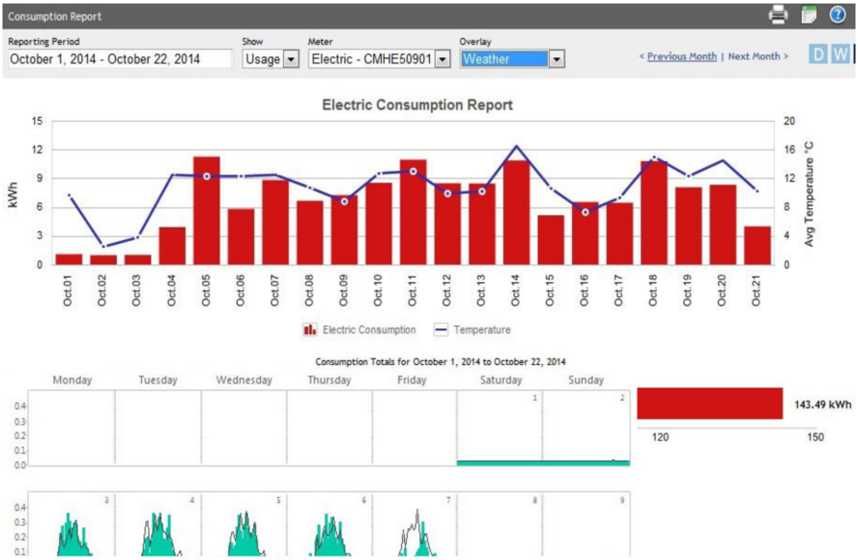

Figure 5. Data analysis report of smart electricity meters under IBA architecture.

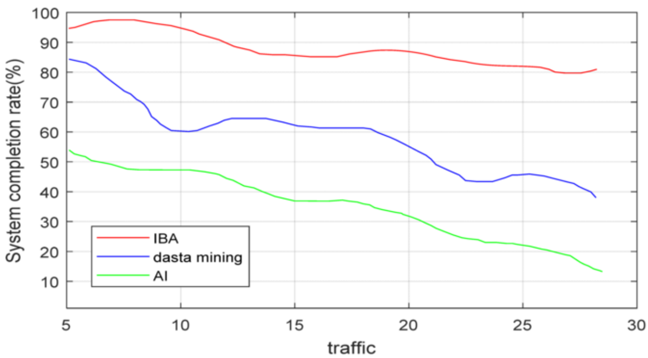

Figure 6. Business completion rate of power grid customer service system.

The results of the system efficiency comparison experiment are shown in Table 1. From this table, it can be seen that the power grid operation monitoring under the IBA architecture supports stronger ability to mine information such as the location of distributed nodes, power supply range, topology relationships, and big data of large-scale power grids from the dimensions of geographical spatial distribution and logical hierarchical structure, resulting in better work efficiency.

Table 1. Power grid efficiency under IBA architecture

System	Working efficiency(%)
IBA	95.67
AI	90.21
Data mining	87.89

5. Conclusion

The smart grid application based on IBA architecture can provide decision support and intelligent functions. By analyzing and mining big data, applications can provide real-time power load forecasting, fault diagnosis, energy optimization, and other functions, helping power managers make more accurate and efficient decisions. This article combines the IBA architecture with smart grid applications to achieve intelligent power management and operation. The main processes of the system include IoT data collection, big data mining and analysis, and human interaction. The feasibility and effectiveness of the system are demonstrated through specific cases. The experimental results indicate that this scheme can achieve comprehensive monitoring, analysis, and optimization of power equipment and data through the integration of the Internet of Things, big data, and artificial intelligence. Moreover, in the practical application of smart grids, it can effectively improve the efficiency, reliability, and sustainability of power systems, thereby providing strong support for the development and application of smart grids.

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