Discussion and Study of Technical Route of Smart Power Plant of Thermal Power

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Abstract: Digital smart power plant is an important development direction of thermal power technology. Smart thermal power plant technical route and development direction is presented considering characteristics of production and management of thermal power enterprises. The smart thermal power plant’s system framework is discussed. The key technical field of smart thermal power plant is studied. An open-ended smart thermal power plant technical system including 5 technical platforms of smart data, smart safety, smart producing, smart operation, smart integrated management, is summarized. Meanwhile, the development status of key technologies of diverse systems and functions is discussed, the future development direction of key technologies is presented constructively, and three principled suggestions on the construction of smart power plant are presented finally.

1. Introduction

The national energy development 13th Five-Year plan has pointed out that should speed up the energy technology innovation and promotion, actively promote the "Internet +" smart energy development [1]. The Strategic Action Plan for Energy Development (2014-2020) has pointed out that should implement the plan of upgrading and renovating coal-fired power plants. Strive to reduce the coal consumption of power supply to about 300 grams of standard coal per kilowatt hour for existing 600,000 kW and above units within five years [2]. The Implementing Plan of Energy Equipment Made in China 2025 points out that should promote to tackle the intelligent control system key technology of coal-fired power plants, research and develop the ultra-supercritical units intelligent control system based on internet technology and intelligent equipment, and adopt the advanced control technology, real-time optimization technology, large data mining technology, high efficiency and low pollution operation technology. Research and development of coal-fired power plant remote diagnosis and monitoring system, construct the large data center and cloud computing platform, which can provide the guidance and decision-making basis for operation and maintenance [3].

At present, domestic experts, scholars and researchers have done some research on the intelligent power plants concept, structure, system and some key technologies [4-8], including the study of thermal power smart power plants key technologies and technical routes [9-10]. So on the basis of previous research, taking the application architecture as the breakthrough point, combining the top-level design of thermal power enterprises production and operation and the actual situation of the development of key technologies, we will discuss the whole industry key technologies and development directions, and puts forward the thermal power intelligent power plants overall construction technical route in
2. The Application Architecture of Thermal Power Intelligent Power Plant

Usually, the system architecture of smart power plants is composed of smart sensors and smart hardware, data access, data fusion, application basic services, function application and interaction, etc. Different thermal power plants can establish corresponding application architecture according to their own needs. Based on the typical application scenarios of thermal power plants and the organizational settings of typical thermal power plants, it is recommended that the application architecture of intelligent power plants be divided into five technical fields: intelligent data, intelligent security, intelligent production, intelligent management and integrated intelligence management, as shown in Fig.1.

3. The Technical Route of Thermal Power Intelligent Power Plant

Infrastructure security, production security and network information security.

3.1 Intelligent Data

The foundation of the construction of smart power plants is Standardized, unified and integrated plant-wide data fusion platform. So we can respectively focus on digital design and integration of data platform during the design construction and operation stage.

3.1.1 Digital Design.

The digital design of intelligent power plant can be accompanied by the life cycle of power plant. It can provide clear and accurate display of position, parameters and status of three-dimensional digital system/equipment/parts. It can realize the linkage between three-dimensional model and digital files of plant equipment, and realize the unification of production and operation data.

Considering the application scenarios of digital technology and three-dimensional technology in thermal power plants, digital design can be divided into digital archives, three-dimensional digital interaction, three-dimensional modeling design, four-code integration of the whole plant, digital transfer, three-dimensional models real-time data display, etc.

Now, the key technologies of thermal power intelligent power plants field to be solved are efficient three-dimensional interactive engine and advanced three-dimensional modeling technology, which are not only the basis of digital design, but also the premise support of personnel positioning, three-dimensional training and other technologies.

1) Efficient three-dimensional interactive engine

Efficient three-dimensional interactive engine is based on efficient algorithms, high-speed chip technology, high-speed network, efficient edge rendering and cloud rendering technology. Unity3D, which is widely used at home and abroad, is the mainstream commercial three-dimensional interaction engine. In addition, there are many open source three-dimensional engines, such as OGRE. In order to adapt to the characteristics of the power industry, some domestic enterprises have begun to develop three-dimensional interactive engine of independent intellectual property rights, which can promote the technological progress in power industry.

2) Advanced Three-dimensional Modeling Technology

There are two main modes in three-dimensional modeling: feature-based modeling and reverse modeling based on three-dimensional point cloud. Reverse modeling based on three-dimensional point cloud is mainly used for stock units with long operation time. Compared with feature-based modeling, three-dimensional point cloud modeling can more truly reflect the equipment situation, but the data and computation of three-dimensional point cloud reverse modeling are huge. In recent years, domestic and foreign research institutions and enterprises have begun to consider the combination of three-dimensional point cloud modeling and artificial intelligence technology to achieve point cloud-based feature modeling, which can significantly reduce the data volume of 3D modeling and improve the interaction efficiency.
3.1.2 Integrated Data Platform.

The purpose of establishing an integrated data platform is to get through the data islands in many links of production and operation, which is the important part of data management in intelligent power plants. The key technologies of establishing integrated data platform include efficient distributed database system, structured and unstructured data management, real-time data and relational data management, unified data standards, etc. By establishing an open and unified data standard, a data platform integrating data collection, storage, processing and analysis will be built. And the data value will be deeply mined, so as to realize the integration and intercommunication of thermal power plants running, equipment, fuel, operation and other data [11].

3.2 Intelligent Security

The purpose of thermal power intelligent safety is to ensure the safety of personnel and equipment in the construction and production of thermal power plants, as well as the safety of network and data interaction process. According to the different time stages and application space, intelligent security can be divided into three directions: infrastructure security, production security and network information security.

![Application framework of smart thermal power plant](image)

**Fig.1** Application framework of smart thermal power plant

3.2.1 Infrastructure Security Management.

During the capital construction period of thermal power plants, the establishment of rules and regulations, personnel training, installation and use of equipment are in the initial stage. So establishing a set of mature engineering safety support system in the stage of capital construction and fully applying the intelligent and mobile capital construction safety management technology, will bring about an overall improvement of the capital construction safety management level.

Considering the factors of engineering construction safety, quality, progress and cost [12], reasonable deployment and implementation of the functions of four major controls, intelligent access control, electronic fence, construction machinery and equipment management, personnel three-dimensional...
positioning, outsourcing management, automatic vehicle identification and illegal behavior identification management will significantly improve the safety management level of capital construction process.

Personnel Positioning Technology

Personnel positioning technology should be combined with site construction needs, considering positioning accuracy and construction cost, and selecting appropriate personnel positioning technology. The accuracy and cost comparison of different types of personnel positioning technology is shown in Fig. 2.

Fig.2 Precision-cost chart of positioning technology

Ultra-wideband positioning technology (UWB), is quite different from traditional communication positioning technology, analyzing the position of tags generated by multiple sensors by using AOA and TDOA location algorithms. Assuming that the target sends out a signal, two nodes a and b receive the signal, so the corresponding TDOA value is computed as:

$$\Delta t_{ab} = t_a - t_b$$  \hspace{1cm} (1)

Then can get the distance difference between the target and the node by:

$$\Delta d_{ab} = d_a - d_b = v(t_a - t_0) - v(t_b - t_0) = v(t_a - t_b)$$ \hspace{1cm} (2)

Suppose the node coordinates are \((x_a,y_a),(x_b,y_b)\), and the distance difference between this two nodes is \(\Delta d_{ab}\), then the locked target function is as:

$$[ (x - x_a)^2 + (y - y_a)^2 ] - [ (x - x_b)^2 + (y - y_b)^2 ] = \Delta d_{ab}$$ \hspace{1cm} (3)

In the practical application of this technology, multi-group measurement parameters of multiple nodes are adopted, and the least square method is used to reduce the error \[^{14}\]. UWB has the advantages of high security, high resolution, strong penetration and low system complexity, and its positioning accuracy can reach centimeter level \[^{15}\].

Comprehensive Image Recognition Technology

As a development direction of image recognition, comprehensive image recognition technology has combined of multi-field depth measurement and infrared measurement based on reflection time with traditional visible image, which can achieve high-precision recognition in a large scale.

With the rapid development of multi-field depth image, skeleton recognition, biology recognition and the maturity of pattern recognition algorithms for deep learning, human recognition, object recognition, three-dimensional body perception and other technologies will become a hot research direction in the intelligence and security field.

3.2.2 Production Security Management.

Intelligent safety management in production process includes face recognition, intelligent two-ticket, intelligent access control, outsourcing management, error prevention interval, and automatic safety warning and so on. Different from engineering construction, production safety requires higher execution requirements for 25 countermeasures, technical supervision, intelligent two-ticket operation and identification of on-site violations.
3.2.3 Network Information Security.

At present, domestic power generation groups are competing to deploy large centralized data centers, integrating all the data of planning, construction, planning operation and production management, which can effectively promote the application of large data in thermal power enterprises, but also pose new challenges to the network information security of power generation enterprises. Thermal power enterprises need to constantly update network information security technology to comprehensively enhance network information security capabilities.

Network information security can be divided into software security and hardware security. Software security mainly includes different types of data encryption and decryption technology; hardware security is mainly achieved by installing physical isolation between networks. Using advanced encryption technology and information security framework, can carry out the hierarchical management of access rights to data resources and information processes, so as to realize data security, application security, terminal security, network security and border security [16].

3.3 Intelligent Production

Comprehensively considering the different stages of thermal power production, the thermal power intelligent production can be divided into four directions: intelligent measurement and control, intelligent maintenance, intelligent operation and intelligent heating. Through the implementation of relevant advanced technologies, the safety, economy, reliability and environmental protection of the unit operation can be optimized, and finally the optimal production efficiency can be achieved.

3.3.1 Intelligent Measurement and Control.

The purpose of intelligent measurement and control is to apply advanced technology to the whole process of measurement and control in thermal power plants, and obtain important parameters which are difficult to be measured directly in real time; to solve the problems that are difficult to be solved manually by using intelligent robots, so as to improve the real-time performance of primary parameter measurement and equipment fault detection; to achieve the regulation quality of controlled parameters by using advanced algorithms and control strategies is far superior to that of power grid and environmental protection assessment requirement[17].

From the point of production process and technology application, intelligent measurement and control can be divided into intelligent measurement, intelligent equipment, intelligent control, intelligent robot, etc.

Intelligent Measurement Technology

On-line coal quality measurement technology. The development of laser measurement technology breaks through the limitations of traditional ray measurement technology and infrared spectroscopy technology in safety and application scenarios, and realizes more efficient on-line measurement of coal quality. Through the correction of moisture data, the measurement results of laser scanning are more accurate.

Boiler CT technology. Through combustion image recognition, laser detection, acoustic detection and other technologies, the three-dimensional spatial distribution in the furnace online measurement of temperature field and velocity field can be realized. And the accurate establishment of three-dimensional combustion mathematical model is the technical basis for accurate combustion regulation.

Intelligent soft sensing technology. Through the fusion of mechanism model and data model, can realize the accurate modeling and soft sensing of key parameters. This technology can be widely used to measure the coal calorific value, the coal elemental composition, the coal mill primary air volume, the pulverized coal concentration, the coal mill load, the coal mill material level, the flue gas oxygen content, the NOx concentration at the entrance of SCR reactor, the fly ash carbon content, and the enthalpy of exhaust steam of steam turbine [9].

Fieldbus Technology

Fieldbus technology can realize signals bidirectional transmission, provide equipment status, range, configuration, alarm, diagnostic information and historical statistical data, and realize sensing
measurement, compensation calculation, engineering volume processing and basic control functions\cite{18}. The main protocols of fieldbus technology include Profibus, Modbus, EtherCAT, Lightbus and so on. Moreover, the fieldbus technology under Profibus protocol has gradually been widely used.

APS one-button boot

APS technology greatly reduces the operator workload and misoperation during start-up and shutdown process, and improves the units load response rate. With the improvement of equipment reliability, breakpoint settings can be gradually reduced and applied to all stages from start-up & shutdown to daily production and operation. Which is the APS technology development and application direction, and the important guarantee for intelligent power plant operation.

Intelligent Robot Technology

Through the integration of composite detection technology, autonomous navigation and intelligent positioning technology, motion attitude control technology with robot, can apply the detection robot, inspection robot, maintenance robot and unmanned aerial vehicle in intelligent power plant. Due to the complex environment of thermal power plants, there is still much room for improvement of intelligent robot in the technical maturity, equipment reliability, and implementation effect and cost reduction.

3.3.2 Intelligent Maintenance.

Intelligent maintenance can change the traditional maintenance mode by applying intelligent equipment, advanced measurement, intelligent early warning, intelligent diagnosis and remote diagnosis technology to the formulation of condition-based maintenance strategy and the implementation and management of maintenance process, so as to improve the level of maintenance management and optimize the maintenance cost. Starting from the maintenance process and mode, intelligent maintenance can be divided into intelligent early warning, expert diagnosis, remote diagnosis, condition maintenance and other functions.

Condition based maintenance (CBM) is one of the key technologies of intelligent maintenance. It is different from the traditional calibration and repair, evaluates the condition of equipment by means of monitoring, analysis and diagnosis, and arranges maintenance items and maintenance cycle reasonably according to the health status of equipment. It mainly covers two parts: condition monitoring and condition evaluation. Through the implementation of condition-based maintenance, the scientific optimization of maintenance items, maintenance cycle and maintenance costs can be achieved, and the economy and safety can be improved.

3.3.3 Intelligent Operation.

The purpose of intelligent operation is to change the traditional operation and patrol mode, solidify human wisdom with machines, and realize fine operation by applying integrated information platform, plant-wide data fusion, operation optimization, artificial intelligence and other technologies to unit operation flexibility, environmental protection facility optimization, deep peak shaving and consumption difference analysis. Intelligent operation can be divided into main and auxiliary machine operation optimization, unit economic consumption difference analysis, unit flexibility and depth peak shaving, environmental emission optimization, intelligent inspection and other functions.

Considering the current technology maturity and application effect, the key technologies of intelligent operation can be focused on are MR and AR technology, unit flexible operation technology, deep peak shaving technology, ultra-low emission technology and intelligent patrol inspection.

3.3.4 Intelligent Heating.

Base on the development of intelligent park and multi-energy co-generation technology, the realization of cogeneration function in thermal power plants has become an important development direction for the single power generation enterprise. This development direction contents are including that integrating data and business of heat source, heat network, heat station, user, charge and customer service systems, building large data center of intelligent heat network, strengthening
collaborative sharing of business data and realizing intelligent heating through coordinated dispatching of source and network load.

Considering the heating system coverage and technical development direction, intelligent heating can be divided into heat network intelligent dispatching, heat network intelligent patrol inspection, heat load real-time adjustment, heat network one pipe to the home, peak shaving and heat storage functions.

3.4 Intelligent Management

The purpose of intelligent management is to realize the wisdom of fuel management, marketing and decision-making of the whole plant, so as to make fuel procurement, power marketing and business decision-making more accurate, rapid and efficient.

According to the different professional fields, it can be divided into two directions: intelligent fuel and intelligent marketing.

3.4.1 Intelligent Fuel.

Considering the fuel management process, intelligent fuel management can be divided into such functions as unmanned sampling, digitized coal yard, accurate coal blending, coal price analysis and prediction. In the field of fuel management, the key technologies of intelligent fuel should be focused on include digitized coal yard and unmanned sampling.

Digitized Coal Yard

Through the application of laser positioning technology, network communication technology, advanced algorithm technology, multi-sensor integration, data acquisition and other technologies, the digital management of fuel procurement, transportation, acceptance, storage and coal blending in thermal power enterprises is realized [20]. Through information, automation, three-dimensional visualization management of coal storage information, coal yard equipment, operators, can provide the strong data support for lean blending coal combustion.

Unmanned Sampling

Through intelligent robots and automation equipment, the whole process of "mining, manufacturing and industrialization" can be managed without human beings. Through the automation equipment, the artificial uncertainties are eliminated, and the coal samples are automatically prepared and checked by unmanned sample preparation, thus realizing the function of proofreading on-line analysis results.

3.4.2 Intelligent Marketing.

By combining large data analysis with artificial intelligence forecasting technology, it can be applied to load forecasting, market price forecasting, bidding assistance and intelligent management decision-making in the power market to realize the wisdom of marketing.

Considering the trend of power market reform and the characteristics of thermal power plant operation, intelligent marketing can be divided into load forecasting, cost analysis, price forecasting, bidding assistance, business decision-making and other functions.

At present, the key technologies of thermal power plants marketing field are included with load forecasting technology and power cost analysis.

Load Forecasting Technology

Power load forecasting technology has experienced three stages of development: experience, tradition and artificial intelligence. With the development of machine self-learning and fuzzy forecasting technology, power load forecasting can consider many factors such as season, temperature, humidity, holidays, users and so on. At present, cloud computing and big data platform are the important directions of power load forecasting technology [21].

Power Cost Analysis

The cost analysis technology of power consumption in thermal power plants is still in the research stage. The difficulty of this technology is to analyze and optimize the cost of fuel power consumption, and calculate the cost of environmental protection (environmental protection consumables, power consumption of environmental protection equipment, etc.), auxiliary power consumption,
maintenance and repair cost, etc., as shown in Fig. 3.

![Fig.3 Cost per kilowatt-hour analysis of Power Plant](image)

Through on-line measurement technology, high-precision modeling technology, machine learning algorithm and other technologies, the analysis and optimization of electricity cost can be realized. On this basis, the functions of fuel procurement guidance, coal blending, combustion optimization, operation optimization, cost analysis and prediction can be realized.

3.5 Integrated Intelligence Management

The purpose of intelligent integrated management is to realize the wisdom of the daily integrated management process of power plants. Considering the coverage of integrated management, it can be divided into four directions: digital training, intelligent warehousing, intelligent information and intelligent interconnection.

3.5.1 Digital Training.

Digital training provides equipment installation and maintenance training for maintenance personnel and digital condition simulation training and operation guidance for operators through the application of three-dimensional scene equipment disassembly, equipment process simulation model, virtual reality (VR) / augmented reality (AR) / mixed reality (MR) and other interactive technologies.

According to the training needs of thermal power plants, digital training can be divided into visual intelligent training, digital simulation training, VR/AR/MR application and other functions.

3.5.2 Intelligent Warehousing.

Intelligent warehousing is an important basis for intelligent management of thermal power plants materials. Through advanced management strategy and network information technology, a warehouse management control network system is constructed to collect, process, analyze and exchange warehouse information, and realize the whole interactive intelligent management from transportation to storage.\(^{[22]}\)

According to the characteristics of warehousing management in thermal power plants, intelligent warehousing can be divided into intelligent management of spare parts, replacement and disposal of waste materials, and joint reserve of materials between power plants. Mobile application, wireless radio frequency identification, internet of things and large data analysis technology are applied to the
intelligent management of spare parts, the Federal Reserve between power plants and the management of waste materials, so as to reduce the cost of material storage, reduce the personnel workload, and ultimately reduce the cost of storage management.

3.5.3 Intelligent Information.

Intelligent information fusion technologies such as "data access, text parsing, mobile sending" and "scheduling strategy, precise push, cross-platform mobile client" can realize automatic push of messages, and actively and accurately deliver key information to users.

According to the different types of information in thermal power plants, intelligent information can be divided into production information push, operation information push, safety information push, operation information push and other functions.

3.5.4 Intelligent Interconnection.

Through the technology of power networking, energy efficient transmission, decoupling and optimization of cooling, heating and power, we can promote the flattening and speeding up of power energy supply system, promote the mode change of energy production and consumption, increase the proportion of renewable energy consumption, further promote energy saving and emission reduction, realize the coordinated transformation of thermal power plants from single generation to multi-energy varieties, and from indiscriminate supply to demand-side solutions. Which will form an ecosphere of intelligent interconnected supply and services of multiple energy resources.

Intelligent interconnection can be divided into multi-energy interconnection, multi-energy complementarity, network source-load interaction and other functions.

Thermoelectric decoupling technology is one of the key technologies in intelligent interconnection. Thermoelectric decoupling of heat supply unit is realized by zero output of low pressure cylinder, absorption heat pump, heat storage and high back pressure operation, which improves the flexibility of energy supply.

4. Conclusion

Combining with the above intelligent power plant technical route, this paper suggests that the construction of intelligent power plant should follow three principles: first, according to the power plant digitization level, personnel status and production and operation needs, take into account the technical maturity and the economy of implementation, and with some emphasis; second, it should conform to the local power market policy, including bidding for power grid access, power auxiliary service grid; environmental protection emission standards, which should be carried out in stages and in an orderly manner. Thirdly, on the basis of the implementation of pilot power plants, construction experience should be summarized and the system structure of smart power plants should be continuously improved, so as to continuously improve the construction and management level of smart power plants.

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