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Construction of digital twin ecosystem for coal-fired generating units

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Construction of digital twin ecosystem for coal-fired generating units

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Abstract. With the development of big data, cloud computing, Internet of things, digital twin and other technologies, the deep integration of these technologies with the energy industry is becoming the demand of production management progress, intelligent power generation has become the trend of development in energy industry.. This article gives an overview of the digital twin ecosystem of coal-fired generating units. The construction of the digital twin ecosystem is carried out from the overall architecture, and it is given a detailed introduction to DCS interface architecture, communication architecture. The digital twin ecosystem can realize real-time twins, predicting twins, simulating twins, and state evaluation, monitoring and early warning, fault diagnosis, optimization guidance, three-dimensional visualization and other functions, which can provide a predictable and visualized big data monitoring platform for real-time monitoring of the entire process of power plant operation, transparency of operation management, and timely discovery of equipment status.

1. Introduction

Digital twin technology makes full use of data from physical models, sensor data, operating history to complete the mapping in the virtual space, and it could reflect the full life of the corresponding physical equipment cycle process [1-4]. The application of digital twin technology in the field of power generation has several advantages. First, the capital intensity of power production is relatively high, and traditional technologies are close to the bottleneck. So further improvements which are taken by digital twin in safety, reliability and economy have high direct and indirect benefits; second, power generation equipment has amount of basic measurement points and data support, so it has relatively standard after-sales and maintenance specifications; third, although there is no direct digital twin typical application case for power generation equipment, but the research on fault diagnosis, big data application, artificial intelligence and other research has extensive theoretical and practical foundations, which all belong to the twinning category. Therefore, it is feasible and general to carry out research on the key technology of twins in the power generation equipment and build a digital twin system for power generation equipment.

The concept of digital twins was first proposed by Grieves of Michigan State University in 2003. He believed that a virtual entity connected to the physical entity can be constructed in the virtual space through the data of the physical entity, which can achieve better product lifecycle management. However, it had not received widespread attention due to technical limitations at that time. Until 2010, the U.S. Air Force Research Laboratory officially mentioned digital twins in a speech. During the same period, the National Aeronautics and Space Administration (NASA) and General Electric realized the value of the concept of digital twins [5]. In April 2013, Germany proposed the "Industry 4.0" strategy. In June of the same year, General Electric proposed the Industrial Internet Plan. Subsequently, the Industrial

Internet Alliance of the United States is formed, with Cisco, IBM, Intel and other companies [6]. And one of the alliance's research strategies is the digital twin.

In 2015, the Industry 4.0 Institute recognized the importance of the concept of digital twins and began to join the research on digital twins. In May 2015, China formally proposed "Made in China 2025". In the follow-up research on the Industrial Internet, the concept of digital twins has attracted more and more attention from all walks of life. In the three years from 2017 to 2019, digital twins were listed by Gartner as one of the top ten strategic technology development trends.

Uhlemann et al. conducted research on automatic data collection in the industrial Internet, and proposed a concept of digital twin factory for small and medium-sized enterprises [7]. Ahmed Saad and others have studied the digital twin system of the electronic physical system based on the Internet of things. The digital twin can interact with the control system to reduce the network security risk of the distributed control system[8]. D. Ford and others integrated the digital twin technology into the research on the community disaster management of smart city[9]. A simulation iteration of the digital twin model is used to evaluate policies to reduce loss of life and property, thus guiding community leaders to make optimal decisions, thereby guiding community leaders to optimize decision-making. Tao Fei, Ma Xin and others released the digital twin standard system in 2019 [10], and proposed a five-dimensional model of digital twin [11], which are physical entities, virtual entities, connections, twin data, and services. Song Yue et al. proposed a digital twin model to solve the problem of performance degradation prediction caused by multi-length coupling in the field of photoelectric detection [12]. Lu Jianfeng, Wang Sheng and others discussed the digital twin technology of smart workshops from different aspects such as model, data, and application, and analyzed the technical support of the industrial Internet for the digital twins[13].

The main function of the digital twin is to establish a reliable real-time and comprehensive connection between the physical entity and the virtual entity, which is the basis of intelligent manufacturing [14]. According to the interaction of the digital twins between the physical entity and the digital world, the value of real-time data in production process is mined, which provides abundant models and data for intelligent decision-making process and provides optimization guidance and fault early warning service for production process. At present, digital twins have had a huge impact on industrial innovation in the industrial field.

2. Materials and Methods

Digital twin could combine the characteristics of coal-fired generating units and technological innovations of artificial intelligence, big data, knowledge logic, real-time simulation, etc, to explain the key equipment and thermal system of the power plant. The basic concept of the digital twin ecosystem (as shown in Fig.1) is to form a real-time twin system that connect with a physical unit and a virtual mirror, to achieve dynamic prediction and iterative optimization of relevant parameters of the unit or system operation, and to provide operators and equipment maintenance personnel risk early warning, fault diagnosis and intelligent optimization guidance. And it will provide managers with intelligent decision-making and producers with intelligent diagnosis, thereby the unit can improve the level of intelligent operation.

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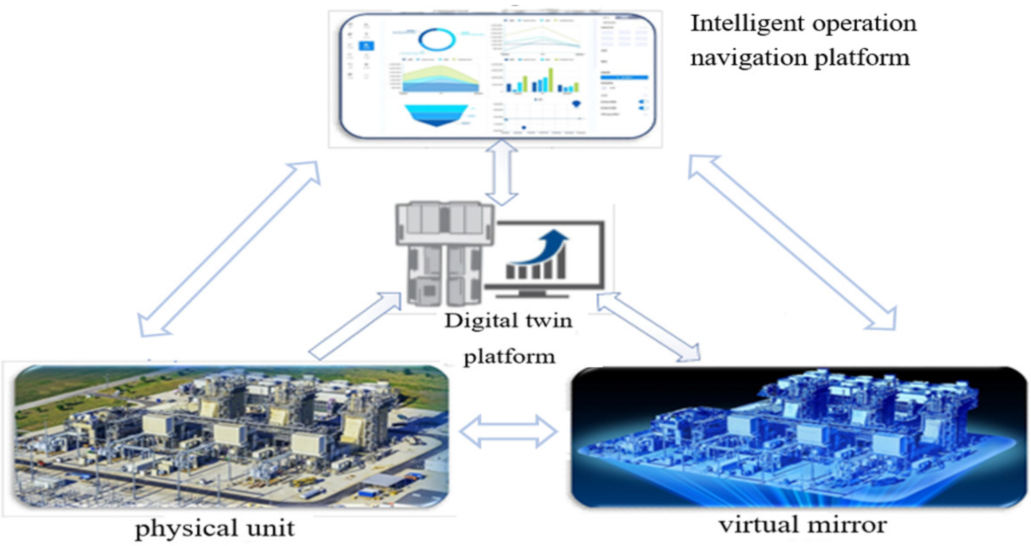

Figure 1. Schematic diagram of the digital twin ecosystem

2.1 Overall architecture

The overall platform architecture of the digital twin system [15,16] is mainly based on the virtual DPU to achieve real-time synchronization between DCS synchronization mirroring with the real DCS. Based on knowledge logic, artificial intelligence and big data analysis technology, we have established mirror of key equipment in thermal power plants, such as coal mill and feedwater pump. Through the real-time dual simulation platform, the twin can realize real-time dynamic accompanying simulation of key equipment and systems, and predict and optimize simulation in different operating scenarios. Twin simulations could offer operators to actively trigger operations or logic modifications according to current working conditions.

The intelligent operation navigation platform is bidirectionally connected with the twin simulation platform and the thermal mirror model. It is responsible for the direct needs of production and operation, and intelligently helps the operator in the fields of monitor, risk early warning, fault diagnosis, quantitative assessment and optimized operation guidance. In this system, the model output of the digital twin platform is fed back to the DCS control system, and the visualization of each function is realized through the intelligent operation navigation platform. The overall platform architecture of the digital twin system is shown in Fig.2:

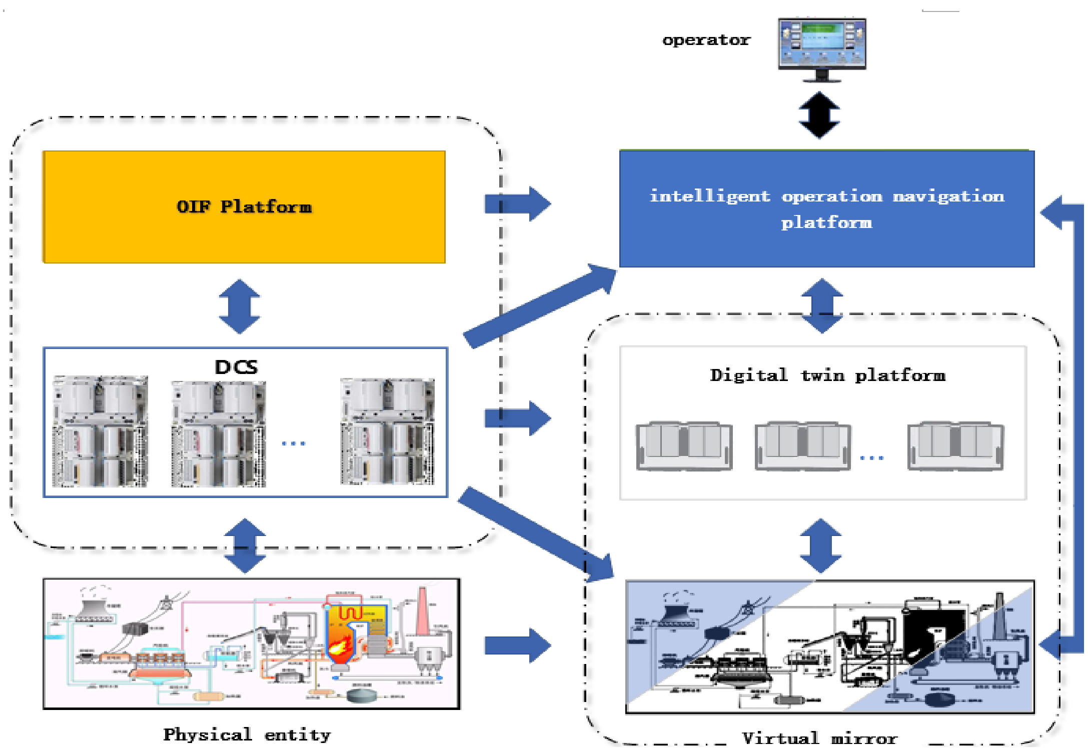

Figure 2. The overall platform architecture of digital twin ecosystem

2.2 Construction of the digital twin ecosystem

According to the digital twin framework, the construction process of the main digital twin ecosystem includes the following parts:

The first is the communication part of DCS (Fig.3). DCS is a terminal that provides real-time data sources and runs the current actual operation monitoring. The digital twin ecosystem needs to take safety and the convenience of operation guidance into account, which adopt a conservative information security architecture to help the system keep stable transmission. Therefore, the communication interface between the digital twin platform and the DCS should take the stability and speed of data transmission as the principal demand point.

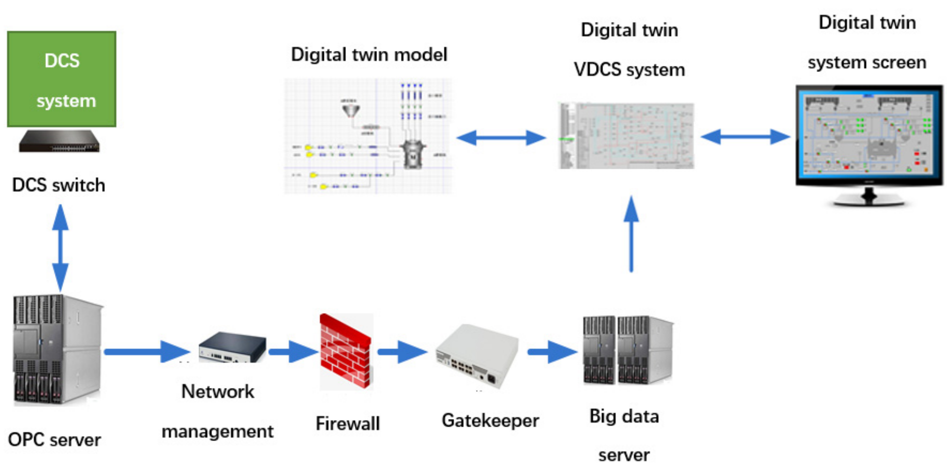

Figure 3. Communication architecture

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Secondly, based on the thermal mirroring model of the actual unit, a DCS synchronous mirroring simulation model is established, and a high-precision simulation system of the unit is obtained through the thermal analysis of the actual unit. According to the real-time operating status of each part of the equipment in the thermal power production link, the dynamic concomitancy simulation and optimization simulation of the equipment are realized.

At the same time, the model layer is built on the basis of the unit's DCS system. Based on data analysis, and using methods such as neural networks and machines learning, mechanism model analysis, etc., the goal to enable the operators in decision-making is realized, and the functions such as fault diagnosis, optimization of working conditions, and status evaluation are also realized.

Then, the simulation and model output data realized by the model layer platform and DCS synchronous mirroring are integrated (Fig.4). According to the actual needs of the unit operation, a smart operation navigation platform is established to visualize the digital twin ecosystem. The navigation platform could assist the operation and management personnel in scientific decision-making, and can help to realize the construction of the unit's digital twin ecosystem.

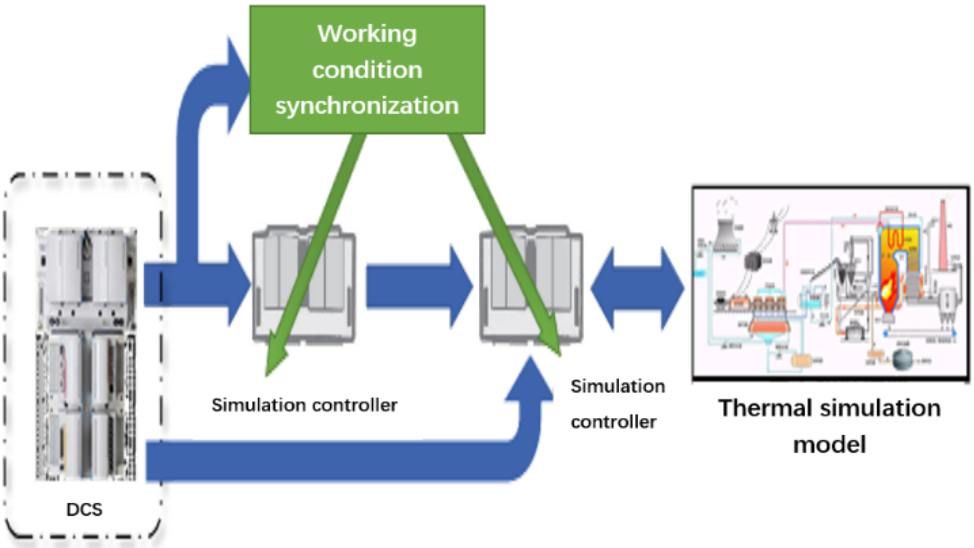

Figure 4. Flow chart of virtual DCS simulation platform

3. Results & Discussion

This digital twin ecosystem takes the equipment and system of a 1000 MW coal-fired generator unit as the research object, and uses the Emerson OIF platform as the interactive interface between the DCS and the digital twin platform. The ecosystem comprehensively utilizes the technologies such as digital twins, data coordination, big data, equipment characteristics, and real-time simulation, artificial intelligence and expert experience technologies, to realize multi-scale and multi-dimensional thermodynamic mirroring of physical equipment, and to realize virtual twins describing the characteristics of physical equipment. Finally, the ecosystem can perform fault diagnosis, prediction and operation simulation on equipment core parameters, and can realize equipment failure warning analyze functions such as early intervention, online guidance for optimal working conditions, and status evaluation. The architecture of this ecosystem mainly includes the following aspects:

3.1 Big data platform architecture

A distributed big data platform is established to integrate real-time production data, which includes production data such as data in the existing real-time database, SIS data, and operating information. The big data platform meets the requirements of stable operation under working conditions such as data collection, storage, and reading.

The platform can provide time series data storage solutions based on opening source big data software. Data preprocessing is carried out through the big data architecture to eliminate abnormal data in order to ensure the availability and ease of use of the data. The model parameters after training are updated by (automatically or manually) changing the model parameter file in the OIF to dynamically update the model.

The specific architecture diagram is as follows:

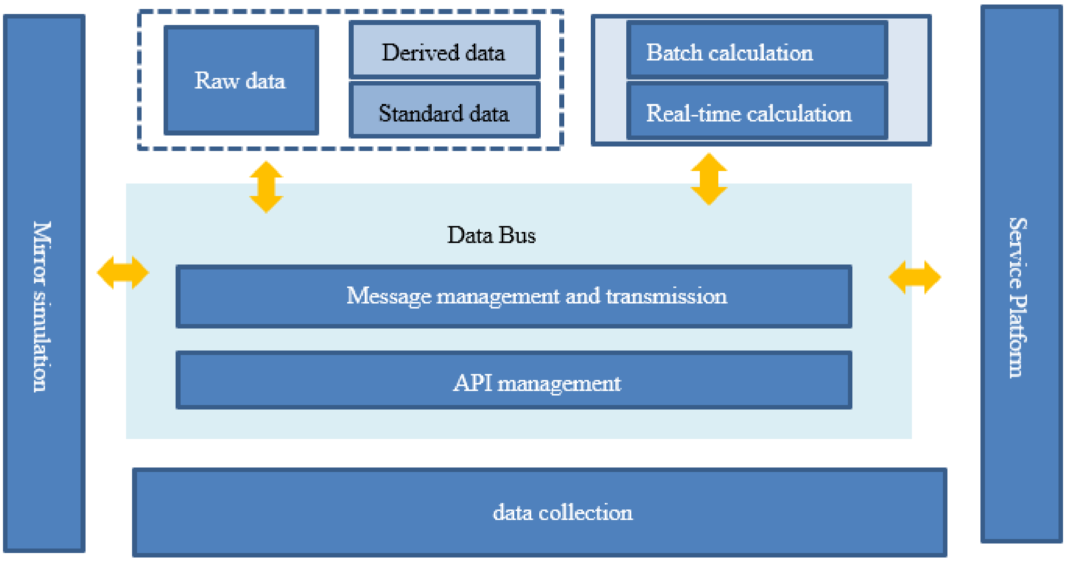

Figure 5. Data platform structure

3.2 System application scenarios

The digital twin ecosystem mainly uses three twin forms, real-time twins, simulated twins, and predictive twins, to realize the application of different time dimensions and different functions of twin data.

Real-time twin: According to the current unit operating status data, the theoretical value of the current time is obtained from the related parameter change curve through the mathematical model or the gray box model. The real-time twin is invoked as a comparison of the current value of the target parameter. When the difference between the simulated data and the current actual operating data of the equipment reaches a certain threshold, it will be judged and analyzed according to the boundary conditions, and warnings and operation suggestions will be given to ensure that the running equipment is not entering the abnormal working condition interval.

Simulated twin: The operator can simulate the twin through the human-computer interaction interface to verify the results of various operations. Firstly, it provides operators with scene exercises, which is based on the historical database, to replay historical working conditions; secondly, it provides customization scenarios, to formulate simulation states and phenomena, and to provide operators with simulations of specified working conditions; thirdly, it is to simulate working conditions that have not actually occurred, especially under extreme parameter conditions, changes in key performance parameters can be found. Fourth, it has real-time learning, memory and update functions, which can optimize and online update various optimal working conditions of different coal, and provide simulation training for operators.

Predicting twins: Digital twins can also predict future conditions through key parameters. When the twins determine a reasonable prediction period based on the characteristics of fundamental parameters, the twins can be predicted to produce key parameters at different time scales in the future. When it is found that the twin prediction data and the development trend of the physical entity parameters have exceeded the expected deviation, an early warning is given, and online quantitative guidance operations or equipment maintenance suggestions are given, and even shutdown inspection suggestions are provided to avoid abnormal expansion.

4. Conclusion

Digitization and intelligence have become an inevitable development trend in the transformation and upgrading of the energy and power field. Realizing the "smart" transformation of coal-fired generating units has become a key technical field for the future development of the power generation industry. The digital twin ecosystem is based on a multi-disciplinary high-tech field, comprehensively using digital twins, data coordination, big data, device characteristics, real-time simulation, artificial intelligence, expert experience and other technologies to perform multi-scale and multi-dimensional twinning of physical devices. Using virtual twins to describe the characteristics of physical equipment, and performing fault diagnosis, prediction and operation simulation on the core parameters of the equipment, the ecosystem can realize early intervention of equipment failure early warning analysis, online guidance for working conditions optimization, and status evaluation.

This article first summarizes the significance of the digital twin ecosystem construction of coal-fired generating units and its realization goals. From the overall architecture of the data twin ecosystem, DCS interface architecture, communication architecture, and DCS synchronization mirroring, the overall architecture and application scenarios of the digital twin ecosystem of coal-fired generating sets are introduced in details. It provides useful exploration for the application and development of the digital twin ecosystem in the field of thermal power generation.

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