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Research on Smart Energy Monitoring and Management System Based on Digital Twin Technology

Xuhui Wang

School of Economics and Management, Beijing University of Posts and Telecommunications, Beijing, China
Email: wxuhui@126.com

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Abstract

Smart energy monitoring and management system lays a foundation for the application and development of smart energy. However, in recent years, the work efficiency of smart energy development enterprises has generally been low, and there is an urgent need to improve the application efficiency, resilience and sustainability of smart energy monitoring and management system. Digital twin technology provides a data-centric solution to improve smart energy monitoring and management system, bringing an opportunity to transform passive infrastructure assets into data-centric systems. This paper expounds on the concept and key technologies of digital twin, and designs a smart energy monitoring and management system based on digital twin technology, which has dual significance for promoting the development of smart energy field and promoting the application of digital twin.

Keywords

Digital Twin, Smart Energy, Monitoring and Management System

1. Introduction

The global energy industry is constantly developing in accordance with the digital age. In this context, accelerating the energy transformation has become an industry consensus. However, the energy industry has institutional, technological and market barriers, making the energy transformation face with challenges. Digital twin technology can establish a precise link between the physical world and the digital world, helping to solve the technical problems faced by smart energy systems, and supporting the accurate simulation and control of energy monitoring and management systems from multiple perspectives.

1.1. Concepts of Digital Twin

Digital Twin (DT) is a behavior that synchronizes virtual and physical states, so that virtual and physical states are "equal". In this way, digital twin is not so much about mirrored reality in the virtual domain (*i.e.* "twins"), as about the desires and actions required to produce virtual reality [1]. Therefore, the definition of the concept of digital twin requires attention to the role of digital twin as "boundary objects", that is, artifacts or concepts that have multiple meanings for different people according to their backgrounds and expertise, as well as the products and effects of boundary work. These are composed of selected features, attributes, conditions and behaviors of models, information and data. These models, information and data are constantly stored throughout the life cycle and can be provided to applications and services to provide a mapping applicable to specific situations, creating and operating network physical systems using the most suitable modeling language. The application basis of digital twin is the code generation infrastructure of information systems, the extensible infrastructure for adaptive digital twin, and the reusable language components for configuration, so that the creation of digital twin can be carried out using a "two-step method": First, software engineers configure the information system using the required modeling language to generate a low-code development platform for digital twin. Second, domain experts use the generated platform to create digital twin. On this basis, the structure and system of digital twinning depend on its application, behavior and capability range. For example, in the field of industrial manufacturing, products can be tracked and monitored during the processing process in order to effectively improve product quality. At the same time, monitoring of machine wear can coordinate maintenance, repair work plans and help reduce planned downtime. However, if unexpected product downstream problems occur or production plans need to be adjusted in a short time, the digital twinning of production resources can be used to rearrange the current production plan and execute the revised production plan. For example, process simulation and machine learning can bring additional benefits. The analysis of existing manufacturing processes using machine learning algorithms can optimize processes to achieve higher stability and quality [2]. It can be seen that the development and design of digital twinning must always take into account the products it represents and the applications to be implemented. In fact, each component can have its own digital twin, which can be aggregated into models, information and data, and represented as systems in accordance with hierarchical representation.

1.2. Key Technologies of Digital Twinning

1.2.1. Digital Modeling

Modeling technology is the basic technology for building digital twinning. The main parts are the system model and analysis, core activities of system development and requirements engineering. In digital twin, all system development results will be reviewed and evaluated regularly. The use case is an important input to put forward development requirements and clarify the system business model in development, and is also the premise of developing the system. Usually, Model-Based Systems Engineering (MBSE) tools can be used to combine the development of digital twin with model-based systems engineering. Throughout the system life cycle, necessary models are created using MBSE tools and made available in the knowledge base of digital twin. It should be noted that the granularity and degree of detail of MBSE models are variable, and must be selected in the manner of "fit for purpose" and "appropriately adjusted to adapt to various contingencies" [3].

1.2.2. Integrated Simulation Verification

The technology of numerical simulation of single-dimensional physical performance or system performance is relatively mature at present. However, for complex practical products, the performance of their runtime involves the comprehensive effect of multiple physical fields and multiple disciplines. Therefore, on the basis of digital models, the co-simulation of a single system or multiple systems to predict and analyze product performance is also an important technology to realize product digital twin.

1.2.3. Other Technologies

To achieve a complete product digital twin, other technologies besides modeling and simulation are also required, such as generative design technology, simulation results calibration technology based on historical data, etc.

Although there is an increasing desire to use digital twin to strengthen the development and implementation of smart energy monitoring and management, little is known about the process of digital twin and their role in the design, planning, and continuous management of smart energy monitoring and management systems. Therefore, this study provides the technical architecture of smart energy monitoring and management system based on digital twin technology, and elaborates on the technical architecture, overall scheme, and system functions of the system.

1.3. Research Status and Trends of Digital Twin Technology for Smart Energy System

The application of digital twin technology in various fields has been developing rapidly, but whether at home or abroad, the application of digital twin technology in energy system is mostly in the stage of exploration and verification. Borchert and Rosen are committed to the research of digital twin simulation modeling of electrical equipment, and have built an interactive platform between users and designers [4]. Ansys Asia Pacific Digital Twin Lab has established a digital twin thermal power plant model based on Flownex design software [5], which provides a technical reference for the engineering design and maintenance of thermal power plants. The research team of Tsinghua University has established a digital twin integrated energy system model using the digital twin CloudIEPS platform, achieving the goal of reducing the operation cost of the energy system [6].

It is generally believed that digital twin technology is especially suitable for complex systems with asset-intensive and high-reliability requirements. The technology has gradually been applied to many industrial fields, with the manufacturing industry as the typical one. Smart energy monitoring and management system is an integrated complex system integrating multiple energy sources, which is highly compatible with the application direction of digital twin technology. However, the current application development of digital twin technology in smart energy monitoring and management system is relatively scattered, and there is no implementation framework for the system. Therefore, this study established the architecture of an intelligent energy monitoring and management system based on digital twin technology, and elaborated the overall scheme, technical architecture and functions of the system in detail.

2. Design of Intelligent Energy Monitoring and Management System

2.1. Overall System Scheme

The intelligent energy monitoring and management system based on the concept of digital twin adopts the intelligent control energy saving control, management and maintenance integration technology architecture of the Internet of Things, multi-network fusion and big data cloud computing technology, artificial intelligence technology, to achieve multi-client data visualization, information graphics, intelligent control in the remote cloud architecture, embedded artificial intelligence inspection model software and energy expert analysis system, from the past manual inspection mode based on control function to active data inspection, predictive maintenance and operation optimization, to find faults in advance, prevent and deal with them, and ensure the safe and reliable operation of the energy system [7]. In the design, the control logic of the system can adopt the way of block connection to transfer information from one block to another block, or adopt script language (this language is common in classic programming language of advanced control algorithm) to provide users with higher level control opportunities to send commands to all connected subsystems. The specific system scheme is shown in **Figure 1**.

As shown in **Figure 1**, the system uses the big data platform as the support of offline computing and storage, formulates unified protocol standards at the information management layer, monitors the intelligent energy application at the real-time monitoring layer, and makes unified access through the general protocol at the intelligent control layer to do a good job of accessing vendor protocols and data.

2.2. System Technical Architecture

The technologies of intelligent energy monitoring and management system based on digital twin mainly include Internet of Things technology, energy prediction technology and high-dimensional data analysis technology.

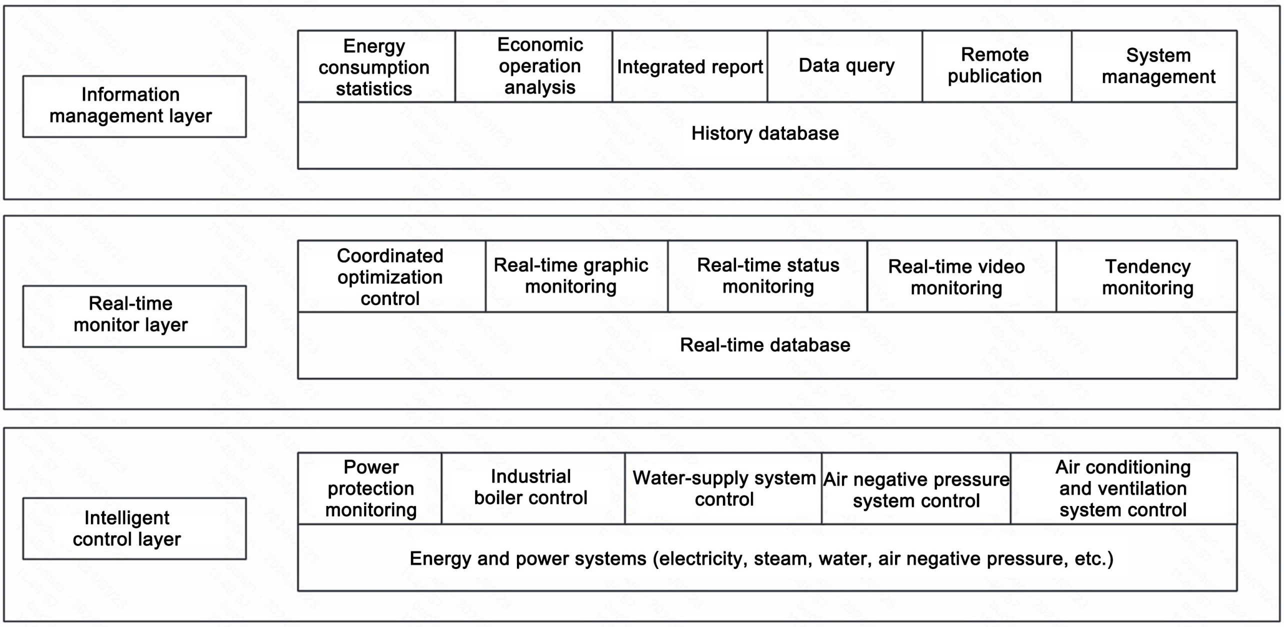

Figure 1. The architecture of smart energy monitoring and management system based on digital twin technology.

2.2.1. Internet of Things Technology

The application of information technologies such as the Internet of Things, together with intelligent devices that can obtain data generated during the product life cycle, and supported by the data mining capability of Artificial Intelligence (AI), is paving the way for data-driven product design, manufacturing and service in the new era. The Internet of Things platform generates data in real time from the physical system, and combines the historical data set of previous energy consumption for the development of the digital twin concept. Similarly, smart power grids and industrial Internet of Things can also provide intelligent sensing and secure transmission networks to build a digital twin framework for ultimate consumers.

2.2.2. Energy Prediction Technology

Robust load prediction models across different time ranges are crucial for the effective operation of power systems, and have been determined to play an important role in optimizing the actual operation of digital twin. Energy forecasting can be roughly divided into short-term, medium-term and long-term load forecasting. Short-term load forecasting allows for the determination of energy consumption 1 hour to 1 week in advance. Medium-term load forecasting usually lasts 2 weeks to 3 years and is mainly aimed at planning, maintaining and scheduling loads in advance [8]. Long-term load forecasting aims to achieve forecasts of future energy demand, thereby enabling long-term understanding of power consumption to formulate, plan and draft effective policies in the national economy. The benefits of using digital twinning for energy forecasting are that the platform runs faster, provides digital twinning approaches for the new energy sector, provides a time dimension for checking benchmark energy, and uses data-driven large-scale models to quickly complete online analysis, etc.

2.2.3. High-Dimensional Data Analysis Techniques

Data cannot be used for energy forecasting in its original form, so it is necessary to understand the key variables affecting energy forecasting to understand the salient features that may affect energy consumption. This involves the process of processing high-dimensional data with data mining techniques. Such data includes forecast and key historical energy data, such as hourly power demand data from utilities, social media, residential information and policies. Weather data includes outdoor temperature, outdoor relative humidity, outdoor air density, ground temperature and total heat gain inside the region, etc. Building energy consumption data includes lighting, heat cycle energy consumption, refrigeration energy consumption, etc. In addition, other characteristics need to be considered, such as workday, weekend, holiday situation, energy profile under different temperatures, time, and consumer demographic information including age, family size and historical consumption data. These are considered to be factors that affect energy dynamics. In order to extract these dynamic informations, efforts need to be made in data preprocessing. Parameters needed for the development of smart energy monitoring and management system based on digital twin are collected from smart meters, weather stations and historical consumption, and consumer-related data are measured, processed and analyzed to develop and optimize energy strategies. In this regard, the application of high-dimensional data analysis technology helps to provide autonomous decision-making for the system.

2.3. System Functional Services

The smart energy monitoring and management system based on digital twin provides the following functional services.

2.3.1. Energy Consumption Analysis and Prediction-Related Services

Smart energy management services have been considered to provide consumers with incentives to save energy and find problems in their energy behavior. Through digital twin, high-precision analysis can be achieved between the virtual world and the physical world, allowing for the prediction of energy consumption at various scales (such as daily, weekly or monthly). In addition, it can also estimate future energy consumption in order to find better energy behaviors and choices, and provide competition-related services.

2.3.2. Energy Management Services Based on Behavior Analysis

Based on users' energy consumption habits, real-time monitoring data of digital twin are collected and analyzed to correct bad energy behaviors and lifestyles. This can be achieved by simply analyzing consumption habits, on the one hand, calculating life behaviors related to energy behaviors, and on the other hand, helping smart energy monitoring and management system effectively carry out digital twin demand side management, while improving the service quality of smart energy monitoring and management system.

2.3.3. Correcting Consumers' Bad Electricity Consumption Habits

Digital twin allow consumer habits to be generated according to different and independent energy consumption patterns of consumers. Through digital twin, smart energy monitoring and management system seizes the opportunity to correct consumers' bad electricity consumption habits in real time. The principle is mainly to analyze the consumption habits of specific users and check whether they are within the healthy consumption range. The method to achieve this goal is to apply non-intrusive device load monitoring technology to decompose the data of smart electricity meters and the use of household appliances of end users, and use similarity measured values to analyze and compare the electricity quality and product energy consumption in a multi-faceted way.

3. Conclusion

Digital twin has become a popular concept in different fields, including energy, public health and infrastructure. Based on digital twin technology, this study clarifies the relevant issues of smart energy monitoring and management system, including system scheme, technical architecture and functional modules, showing the important role of digital twin technology in smart energy monitoring and management system.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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