Application case of digital twin technology in electric power system

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Abstract. The electric power system is an important part of the national economy. Substation, as a core element of the electric power system, has problems such as difficulties to supervise. This paper proposes the use of digital twin technology to solve the problem of regulatory difficulties. Firstly, the mathematical model of substation digital twin is established. Then the digital twin engine is designed based on the model, which realizes real-time orientation of the personnel through UWB location technology, realizes real-time monitoring of personnel, work, equipment operation, and work area through job management, realizes real-time monitoring of production data through equipment data mapping, realizes early warning and rapid emergency response through operation rules. At last, the prototype system is developed to verify the function. The experimental results show that the system can effectively improve the supervision capability of the substation. This solution can provide a useful reference for systems with similar needs.

Keywords. Electric power system; Substation; Digital twin; Real-time monitoring; Integrated management system

1. Introduction
The power system is an important part of national and regional national economic development plans[1]. With the development of the times, the power systems of countries around the world have been huger and huger, and the management and maintenance of power systems has become more and more complicated [2]. As an important production link of the power system, its safe production plays a very important role in the stable operation of the power systems[3]. Due to the complex internal environmental relationship of the power plant, there are many objective factors in the production process, such as less staff, heavy tasks and dangerous areas, and more regulatory difficulties[4], which bring great challenges to the safety production management of the power plant. In China, there are still following shortcomings in the current management of substation: 1) The personnel environment of substation is complex, and there are often external temporary workers entering the station to carry out operations. Although temporary workers has been trained, they still have insufficient awareness of the danger inside the substation and are prone to accidents. 2) When the staff performs production operations in the factory, there is a lack of real-time supervision on staff's working range, working time and working object. 3) When an accident occurs, the substation cannot make effective emergency measures in the first time. 4) Although the DCS system collects the production data of the equipment, the data is enclosed inside the system and lacks in-depth application. 5) Traditional substations usually have multiple...
management systems, such as monitoring systems, access control systems, and attendance system. Data isolation between multiple systems make it difficult to manage these systems. In summary, the current substation lacks an effective integrated management system to comprehensive manage personnel and activity of production.

Digital Twin, as a new technique, create a virtual model of physical entity through digital methods[5], simulate the behaviour of physical entity in the real environment with the help of data, and use virtual and real interaction feedback, data fusion analysis, decision iterative optimization and other methods to fully reflect the life cycle of corresponding physical entity[6]. Through the deep integration of digital twin and substation management system, the operation efficiency of the management system can be effectively increased, and the production safety can be guaranteed.

In this paper, our team designed a digital twin management system according to practical needs. The implementation details of this system are explained below.

2. Digital Twin
The earliest application of digital twin originated in the Apollo project of NASA[7]. First, establish a digital model of the spacecraft, and ensure the synchronization with the real entity through the data transmission of the sensor. By utilizing this digital model, simulation experiments can be performed during task execution, and this digital model can simulate the real state of entity as much as possible, thereby assisting the astronauts in making the right decision in the event of an accident. In 2003, Michael Grieves, a professor from University of Michigan, first proposed the concept of digital twin[8]. In his article, he believes that a physical entity can be characterized in virtual space by a series of data. And this connection is dynamic, which can effectively simulate the entire life cycle of physical entity[9].

From the definition of digital twin, it refers to be a process and a method that can describe a physical entity’s feature, action, performance and running state. Digital twin is a digital representation of a physical entity[10]. It maps the characteristic attributes of physical entities into virtual space through various digital means, such as design tools, simulation tools, and virtual reality tools to form an extensible, integratable, reproducible, adaptable digital replica[11]. It can not only help people understand the real state of physical entity through this digital replica, but also help people to predict the dangers and conditions of unknown existence and find a better solution.

3. Study on key technologies of digital twin management system

3.1. Requirement analysis of system
The substation has a large plant area, and many staffs work in different areas that the substation management personnel cannot supervise the actual working status of the workers. The production and supervise efficiency are difficult to improve. The running data of the equipment is also stored in the DCS system, and the administrator cannot directly view the running status of the device. The data of multiple management systems in the substation is not coordinated, which increases the difficulty of management. To Sum up, the new integrated management system must achieve the following goals:

- Enable to record the work range, work time and work object of staffs in real time, and can trace the historical behaviour of staffs.
- Enable to divide working areas and electronic fences, and set different permissions to alert if someone who hasn’t been permitted break into permission zone.
- Enable to visually display the running status of the production equipment, and can alert immediately as abnormal data appear.
- Enable to handle all kinds of security alarms, and manage the production operation of the whole plant.
3.2. Modelling of digital twin systems

3.2.1. Establishment of mathematical model. In order to manage staff and equipment in the substation, it is necessary to establish mathematical models of personnel, location information, production equipment, production data and alarm information, then establish a mapping relationship between the real physical world and the digital world. For the personnel, define the entity person Staff as an n-dimensional tuple for recording the factory staff and temporary visitors, as follows:

\[
\text{Staff} = \langle \text{StaffID}, \text{Name}, \text{Age}, \text{Gender}, \\
\quad \text{Type}, \text{Location}, \ldots \rangle
\]

Among them, StaffID is used as the primary key of person, Name is used to record personal name information, Age is used to record personal age information, Gender is used to record personal gender information, Type is used to be record personal type information, Location is used to record personal location information.

Define:

\[
\text{Staff} = \{ \text{Staff0, Staff1, Staff2, ...} \}
\]

It is used to record information of each person entity. For location, define a 5-dimensional tuple as follows:

\[
\text{Location} = \langle \text{LocationID}, \text{LocationX}, \text{LocationY}, \\
\quad \text{LocationZ}, \text{Floor} \rangle
\]

Among them, LocationID is used as the primary key of location information, LocationX, LocationY, LocationZ is used to record location information, Floor is used to record floor information.

Define:

\[
\text{Locations} = \{ \text{Location0, Location1, Location2, ...} \}
\]

It is used to record a series of location information entity. For area, define a 8-dimensional tuple as follows:

\[
\text{Area} = \langle \text{AreaID}, \text{Location}, \text{X0, X1, X2, X3, Floor, Authority} \rangle
\]

Among them, AreaID is used as the primary key of Area information, Location is used to record location information, X0, X1, X2, X3 is used to record area range, Floor is used to record floor information, Authority is used to record authority information.

Define:

\[
\text{Areas} = \{ \text{Area0, Area1, Area2, ...} \}
\]

It’s used to record a series of restricted area entity. For equipment, define an n-dimensional tuple as follows:

\[
\text{Equipment} = \langle \text{EquipmentID, EquipmentName,} \\
\quad \text{Location, Floor, Authority, Datum, } \ldots \rangle
\]

Among them, EquipmentID is used as the primary key of equipment, EquipmentName is used to record name information of equipment, Location is used to record location information of equipment, Floor is used to record floor information of equipment, Authority is used to record authority information of equipment. Datum is used to record production data of equipment.

Define:

\[
\text{Equipment} = \{ \text{Equipment0, Equipment1, Equipment2, ...} \}
\]
It’s used to record a series of equipment entity. For datum, define a 4-dimensional tuple as follows:

```
Datum =< DatumID, DatumName, DatumValue, DateTime >
```

Among them, DatumID is used as the primary key of datum, DatumName is used to record name information of datum, DatumValue is used to record value information of datum, DateTime is used to record generation time of the datum.

Define:

```
Data = {Datum0, Datum1, Datum2, ... }
```

It is used to record a series of data entity. For warning information, define a 5-dimensional tuple as follows:

```
Warning =< WarningID, WarningName, WarningType, WarningTime, isClear >
```

Among them, WarningID is used as the primary key of warning, WarningName is used to record the personal name or equipment name who caused the warning, WarningType is used to record type information of warning, WarningTime is used to record time of warning happened, isClear is used to record if an alert has been processed.

Define:

```
Warnings = {Warning0, Warning1, Warning2, ... }
```

It’s used to record a series of warnings.

3.2.2. Establishment of mapping relation model. After establishing the mathematical model of the completed entity, the mapping relationship of these models is established. The specific mapping relationship as follows:

Person and location

Define:

```
Staff→ Position, as : F_1 (Staff)
```

It’s used to record a piece of location information of person.

Define:

```
Staff→ Positions, as : F_2 (Staff)
```

It’s used to record history location information of person.

Person and restricted area

Define:

```
(Staff, Location) → Area, as : F_3 (Staff, Location)
```

It’s used to record restricted area in which the person is located.

Define:

```
(Staff, Location)→ Areas, as : F_4 (Staff, Location)
```

It’s used to record restricted areas in which the person has been located.

Person and equipment

Define:

```
Staff→ Equipment, as : F_5 (Staff)
```

It’s used to record a piece of equipment which person operates.

Define:

```
Staff→ Equipments, as : F_6 (Staff)
```

It’s used to record equipments which person has operated.

Equipment and data

Define:

```
Equipment→ Datum, as : F_7 (Equipment)
```

It’s used to record a piece of data which equipment produces.

Define:
Equipment $\rightarrow$ Data, as : $F_B \ (Equipment)$

It’s used to record a series of data which equipment has produced.

Person, equipment and warning
Define:

(Staff, Equipment $\rightarrow$ Warning, as : $F_9 \ (Staff, Equipment)$

It’s used to record a piece of warning message which staff or equipment causes.
Define:

(Staff, Equipment) $\rightarrow$ Warnings, as : $F_{10} \ (Staff, Equipment)$

It’s used to record a series of warning message which staff or equipment cause.

![Digital Twin Engine Diagram](Image)

**Figure 1.** System architecture diagram.

4. Design and implementation of management system based on digital twin

4.1. Overall architecture design of the system

According to the actual needs of the management system, the overall framework structure is designed as shown in figure 1. The whole architecture mainly includes digital twin engine, substation environment module, equipment supervision module and personnel positioning module. The whole system establishes the digital replica of the power plant station through the three modules of the substation environment, equipment supervision and personnel positioning. Through the data exchange interface, the digital twin system realizes to manage electronic fence/work area, personnel and its working content, equipment and its status in the substation. The system also can record and alert accidents include
personnel enters restricted area personnel operate equipment in violation, and abnormal production data. The substation environment module mainly realizes the division of the electronic fence/work area and the establishment of the three-dimensional model of the substation, and realizes the limitation of the working range of the personnel by different authority. The equipment supervision module mainly obtains the operation data of the equipment through the DCS system, and then visually displays the operation data of the equipment and the equipment, and sets the authority of the equipment to limit the working objects of the personnel. The personnel positioning module use the UWB indoor positioning technology to locate the position information of the personnel by locating tag and base station at first. And then through personnel management set different authority, thereby confining the work content of the personnel. Finally use 3D visualization to display the working state of the personnel in real time.

4.2. Designation of the database
Before establishing a database, we must first establish an E-R relationship model. According to the mathematical model established above and the entity to be concerned, the E-R the figure that the personnel entity and the locating tag entity form a one-to-one correspondence. The personnel violation information (position abnormality) can form a one-to-one correspondence with the personnel through the positioning tag. Each violation information is paired with the zone of authority. Through such a corresponding form, the detailed information of each violation is recorded, and the offending personnel is quickly determined. In terms of equipment, equipment and personnel and alarm information are established in one-to-one relationship. When an unexpected situation occurs in the operation of the equipment, the abnormal equipment information and the mishandling personnel information can be obtained in the first time.

![E-R relationship model diagram](image)

**Figure 2.** E-R relationship model diagram.

4.3. System display
After the system debugging is completed, the system is deployed to the cloud server, and the second debugging and on-site trial operation are performed.
Figure 3. Initial interface.

Figure 4 shows the operating statues of the equipment and its detailed parameters.

Figure 4. Equipment running status diagram.

5. Summary and forecasting
This paper based on the digital twinning technology and the actual application requirements of the power plant, analyzes and designs the mathematical model of the substation firstly, and build a new substation management system by adding digital twin between the management system layer and production activities layer. The system currently implements the following features:

- Realize full-scale monitoring of the staff in the substation, and record the historical behaviour of the staff.
- Realize setting zone of authority, and record and alert various types of unauthorized actions.
- Realize visualization of equipment production status, and record and alert abnormal production information.
- Realize timely processing of in-substation alarms, and optimized production scheduling in the substation.

At present, the application of digital twin technology in substation is still in a relatively early stage. This system also has a lot of room for improvement, and the following functions can be added in the future:

- Quick alarm for abnormal behaviour of personnel, and optimization of work design through abnormal analysis.
• Rapid alarms for abnormal production, accelerating abnormal reaction capability and processing capacity.
• Deep application of production data to help improve the production efficiency of the plant.

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