Application of Digital Twin Technology in Energy and Power Industry

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Abstract. Constructing digital twin of physical entity and analyzing twin data, and transfer learning method can be used to transfer the characteristics of twin to physical entity for analysis. This paper mainly studies the application of digital twinning technology in the energy and power industry. Aiming at the energy saving and control problem of building energy demand terminal, the fuzzy adaptive PID control algorithm is used to simulate the indoor HVAC system and lighting system, so as to solve the indoor temperature and illumination intensity are greatly affected by the weather, time-varying and unpredictable factors. By comparing with the conventional PID, we can see that the fuzzy adaptive PID controller adjusts faster, the output duty ratio is more accurate, and can achieve better control effect.

1. Introduction

CPS aims to integrate and collaborate organically with 3C (Communication, Control) technologies to achieve the interconnection and interoperation between the virtual and physical worlds and support more decentralized and enhanced production Control. Among them, as an important link or one of the key technologies to realize CPS, digital twinning realizes the digital model mapping from the physical system to the cyber space from the aspects of geometry, physics, behavior and rules to ensure the harmony between the digital world and the physical world. On the basis of constructing the digital model, it can also realize real-time monitoring, data collection, simulation and analytical reasoning of physical objects based on the digital model [1-2]. With the rapid development of the information technology of smart power grid, the connection between information and communication technology and modern power grid is getting closer and closer, which leads to the enhancement of the connectivity and automation degree of power grid, as well as the exponential increase of its scale and complexity. As a result, the modern power system gradually forms a complex system integrating perception, communication and control. In order to support the reliable operation of modern power system, 3C (Computation, Communication, Control) technology is introduced in traditional power system on a large scale. Through this technology, the coupling of Communication system and monitoring system with traditional power system is realized. This is characterized by the integration of Cyber Physical System (CPS) [3-4]. Therefore, from the perspective of CPS, the modern power system has developed into a power CPS composed of the interaction between the physical grid system and the information system, which contains frequent information flow and energy flow exchange [5-6].

With the development of informatization and digitalization, the concept of Digital Twin has been put forward. Digital twin first come from NASA’s Apollo program, in the project, NASA made two identical aircraft, space one mission, another on the earth, accurate simulation of the flight on a
mission in outer space conditions, another spacecraft mission to feedback, the situation of the aircraft on the earth will be fed back to the astronauts so as to make the best choice [7]. With the development of information technology, some scholars began to use computers to simulate real objects in digital space.

In this paper, based on the higher flexibility and other functions and characteristics of CPS enabled production system, and based on the unique attributes and characteristics of digital twin technology, the energy and power control system technology driven by digital twin is studied.

2. Energy Control Based on Digital Twin Technology

2.1. Improvement of Digital Twin Technology

2.1.1 Definition of digital twin

The definition of digital twinning has also changed over the years. In AFRL's definition, digital twin is defined as an integrated system composed of data models, which can deploy the entire aircraft formation as well as a single aircraft [8]. According to the definition of NASA, digital twin is a digital system integrated with multi-physics, multi-scale and probabilistic simulation, which can reflect the actual condition of the real aircraft through simulated physical model, real-time sensors and service history [9]. In GE's definition, digital twins focus on the software representation of assets, which are used to predict and optimize the business, and are composed of data, algorithms and knowledge instead of physical entities [10]. Therefore, there are still many differences in the definition of digital twinning. Different companies may have different understandings of digital twinning due to their different priorities.

2.1.2 Digital twin model

In the process of constructing the digital twin model, the traditional digital three-dimensional model cannot meet the current requirements. In order to promote the development of digital twin and the application of digital twin in many fields, a five-dimensional digital twin model is proposed. Different from the traditional manufacturing industry, which only needs to pay attention to production factors and products, the emerging manufacturing industry also needs to pay more attention to the data, information, knowledge and product services in the production process. Products in the physical world are no longer enough to meet the development of manufacturing industry. Only the combination of virtual and real can comply with the development of the market.

The digital twin five-dimensional model is composed of physical entity, virtual entity, link, twin data and service system. The physical object and virtual model are a pair of corresponding levels, in which the interaction is carried out by the information connection channel. The data generated by physical object, virtual object and service system are collectively referred to as twin data. By analyzing and calculating the twin data, valuable information can be obtained to drive the operation of multiple objects in turn. The whole digital twin model is mutual, and the decision optimization can also promote each other [11-12].

With the digital twin five-dimensional model, the advantages of digital twin are clear. The interaction between information and the physical world is the bridge for the development of digital twins, and virtual modeling is an indispensable part of the process of digital twins. In other words, virtual modeling is the foundation for digital twins to be truly different from traditional manufacturing. Twin data is generated in the process of digital twinning, and analysis of twin data is the driving force of the whole model. Connectivity is also essential for the digital twin model, which holds the data of the whole model and the interaction of information. The ultimate goal of digital twin is to target application service, and digital twin works for application service as a whole. Information collection of physical objects is essential as the primary source of information for digital twinning. By analyzing the digital twin model, the key points of digital twin can be clearly recognized, which provides theoretical support for the subsequent model construction.
When the digital twin model is built, the goal is to build a bridge between the virtual end and the physical end by comprehensively considering the various information of the model, so that the twin can fully reflect the information of the physical entity, and further realize the twin beyond the physical limit and predict the information of the physical entity.

2.2. Energy Demand Terminal Control Method

2.2.1 Fuzzy PID control principle
Fuzzy control is an intelligent nonlinear control system. Different from the traditional control system, it uses the fuzzy controller instead of the traditional controller. One dimensional fuzzy controller is a single input single output fuzzy controller, the control logic is not complicated, the system requirements are easy to achieve, but the control effect is not ideal. Compared with the one-dimensional fuzzy controller, the three-dimensional fuzzy controller has good control effect and performance, but it also has some problems such as complex logic, difficulty in designing fuzzy rules and difficulty in realizing control. Since the two-dimensional fuzzy controller can well reflect the dynamic characteristics of the error signal, the control effect is better than that of the one-dimensional fuzzy controller, but it is simpler than that of the three-dimensional fuzzy controller, so the control system in this paper adopts the two-dimensional fuzzy controller.

2.2.2 Fuzzy PID controller design
The fundamental domain is the actual range of the precise input and output of a fuzzy controller. The fuzzy set theory domain after fuzzification is called fuzzy set theory domain. The theoretical domain of fuzzy sets is generally symmetric, that is, \{-n, -n+1,..., 0,..., n-1, n\}. Theoretically, the more n choices there are, the more elements in the domain, which can both improve the control accuracy and increase the amount of calculated data. In general, fuzzy subsets have better domain coverage when there are about twice as many elements in the domain as fuzzy subsets.

After fuzzing input and output, it is also very important to choose appropriate membership function to describe fuzziness. Triangle membership function is widely used because of its fast calculation speed and strong reliability, so we choose trigonometric function, and we will not consider other functions here. Therefore, the trigonometric membership function is selected to fuzzize the input variables of the fuzzy controller from the basic domain to the corresponding fuzzy domain. The system error and the rate of change of the error are taken as input variables, and the fuzzy conditional statements are obtained through the language variable values.

Completion of work, the on-line adjustment of PID controller parameters, in front of the control, according to a mathematical model of the case, first using optimization method to optimize a set of initial PID parameter, control according to the error e and error change rate ec again when find out the three parameters of PID controller correction, finally according to the following formula to calculate the actual parameters of PID.

\[
K_P = K_{P0} + G_P * \Delta K_P \tag{1}
\]
\[
K_I = K_{I0} + G_D * \Delta K_I \tag{2}
\]
\[
K_D = K_{D0} + G_D * \Delta K_D \tag{3}
\]

3. Controller Simulation Test

3.1. HVAC System Control
Because the temperature of an air-conditioned room is affected by many factors, such as the opening and closing of shutters and doors and Windows and weather factors, it is difficult to describe the control process of room temperature with an accurate mathematical model. By analyzing the model of
air-conditioned room and terminal air-conditioned box, and combining with relevant materials, the mathematical model of temperature control in air-conditioned room is simplified to a typical dynamic transfer function of first-order inertia plus pure lag.

The self-adaptive fuzzy PID controller completes the self-adjustment and self-correction of the PID control variables online through fuzzy reasoning and fuzzy operation on the real-time temperature of the room, and obtains the frequency of the air blower of the air conditioner box to control the air supply volume of the system, so that the room temperature is always maintained at the set value.

The deviation between the terminal room temperature and the set value and the deviation rate of change are taken as the input variables of the adaptive fuzzy PID controller, and the parameter adjustment values of the conventional PID controller $\Delta K_p$, $Am Ki$ and $Ang K_d$ are taken as the output variables. The set value of the air conditioning room temperature in summer is 25℃. According to the summer temperature variation in the north, The room temperature deviation $E$ is set as [-15,15], and the temperature deviation change rate is set as [-10,10].

3.2. Lighting System Control

Due to the time-varying and easy interference characteristics of natural light, it is difficult to complete the detection of actual data, so it is impossible to build an accurate mathematical model for control. In this study, the intelligent dimming system model in related studies was selected.

The self-adaptive fuzzy PID controller completes the self-adjustment and self-correction of the PID control variables through fuzzy reasoning and fuzzy operation on the room real-time illumination, and gets the illumination of the output LED light to control the indoor illumination, so that the indoor illumination is always maintained at the set value.

The deviation between the room illumination intensity and the set value and the deviation rate of change are taken as the input variables of the adaptive fuzzy PID controller, and the parameter adjustment values of the conventional PID controller $\Delta K_p$, $Al K_i$ and $K_d$ are taken as the output variables. The set value of the room illumination is 300lx. The basic domain of room illumination deviation $E$ is set as [-100,100], and the basic domain of change rate of illumination deviation is set as [-50,50].

4. Simulation Test Results

4.1. HVAC Experimental Results

|          | 20  | 50  | 100 | 150 | 200 |
|----------|-----|-----|-----|-----|-----|
| Traditional PID | 4.9 | 22.8| 24.7| 24.5| 24.6|
| Fuzzy PID     | 5.2 | 17.3| 23.6| 24.8| 24.8|
As shown in Table 1 and Figure 1, the effect of conventional PID control and adaptive fuzzy PID adjustment is very good. However, the traditional PID control system has slight oscillation, starting from the 50s to the 150s, and the adjustment time is a little longer than the adaptive fuzzy PID control system by about the 50s. Therefore, the simulated control effect is better, because the system adjusts quickly and steadily, without overshoot, and is stable without oscillation.

The traditional PID controller can basically meet the temperature control requirements of the air-conditioned room when the parameters are reasonable and the system control accuracy is not very high. However, the temperature regulation of HVAC system is complex, and it is difficult to use an accurate but fixed mathematical model to describe it. If there is disturbance, the traditional PID control method is not effective. Therefore, this experiment verifies the effectiveness of fuzzy PID control.

4.2. Experimental Results of Lighting System

Figure 2 shows the illumination intensity response curves of the traditional PID controller and the adaptive fuzzy PID controller in the control room under the condition that the transfer function parameters of the control object remain unchanged and there is no jitter factor. As can be seen from the figure, the effect of conventional PID control and adaptive fuzzy PID adjustment is also very good. However, the traditional PID control system has slight oscillation and overshoot phenomenon. Although the adaptive fuzzy PID control also has a slight overshoot phenomenon, the adjustment time
is much smaller than the traditional PID control system, and the adjustment response is fast. Therefore, the fuzzy control effect is better, because the system adjustment is fast and stable, the overshoot is small, and the stability is no oscillation.

5. Conclusions
With the complexity of the physical network to improve electric power information, maintain the safe and stable operation of power system becomes increasingly important, according to various information security problem caused by the development of intelligent, we should give high attention, and the problems were analyzed, and the only combined with the actual situation, put forward effective solutions, can improve the level of information security management, promote the long-term and stable development of the power system. This paper applies the CPS system building energy system of energy supply and energy demand in the end, use the reliable awareness and precision control of the CPS system, the characteristics of real-time perception within the building on the physical environment, and according to the actual situation for the building of renewable energy production and building HVAC control system and lighting system, so as to achieve the "maximum energy supply, minimum energy consumption, the best comfort" purpose.

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