Power System Clock Synchronization Method Based on Service Interoperability

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Abstract. With the development of power system in recent years, it is changing from the direction of smart grid. It is forming a system composed of a large number of intelligent devices with multiple features, producing a large number of heterogeneous and related data. However, there is the problem of information closure in the system, because different systems and equipment come from different manufacturers, and based on different standards, there will be information closure between each other. So it has become an important topic for the power industry to establish the relationship and form interoperability. In view of the above problems, this paper first proposes a service interoperability architecture, which is used to solve the problem of information closure and promote the efficient collaboration between multiple devices and businesses. At the same time, in the process of service interoperability, due to the real-time and deterministic requirements of data transmission, this paper studies the IEEE802.1AS clock synchronization protocol, analyzes the delay measurement principle and time synchronization principle in the protocol, proposes a clock synchronization method based on IEEE802.1AS and service interoperability, and proposes an OPC UA based clock synchronization method. Finally, the proposed method is proved to be effective in power system.

Keywords: Power System, Information Closure, Service Interoperability, Clock Synchronization, OPC UA

1. Introduction

The power system clock synchronization method based on service interoperability refers to the system based on service interoperability. The equipment that needs clock synchronization in power system should be modeled, so that the interoperability between devices can be realized by calling the service interface, and the existing clock synchronization methods are optimized according to this mechanism so the power system clock synchronization ability will be enhanced.
At present, in the field of IOT (the internet of things), the interoperability of devices is becoming more and more important in the construction of an extensible, adaptable and seamless internet of things network. In the process of establishing interoperability, it can be based on the idea of service-oriented architecture, which is conducive to solving the communication between heterogeneous systems or multiple devices. Clock synchronization technology is one of the key technologies of the IOT, which has important research significance. Firstly, in order to ensure the coordinated work of various devices in the IOT system, it is necessary to ensure high clock synchronization accuracy; Similarly, in the power system, clock synchronization also plays an important role. The power system itself is a time-dependent system, therefore, in the promotion and application of digital power technology in the future, the requirements for time synchronization will be higher.

This paper first summarizes the research status of service interoperability system and clock synchronization method, and then analyzes the combination mode of the two; then proposes the construction method of service interoperability system, and how to realize clock synchronization based on service interoperability, and then analyzes the actual demand of power system and the status and problems of clock synchronization, according to the actual situation of power system In the scenario, the application mode of clock synchronization method based on service interoperability is proposed; finally, the effectiveness of the method is proved by experiments.

2. Related Work
At present, the IOT has attracted the attention of the whole industry. The application of Internet of things technology in power grid can effectively promote the upgrading and transformation of power grid industry [1]. In the traditional distribution network, the data interaction between the terminal equipment and the master station system is to transmit the collected data to the control system only through transmission [2]. In this process, there is no interoperability between the devices. The research shows that the system with interoperability has certain advantages in dealing with large data volume, frequent updating and data intensive situations [3].

At the same time, in the research of clock synchronization technology, the application of clock synchronization technology in the important nodes of distribution network is also the key to achieve technological breakthrough [4]. NTP (Network Time Protocol) protocol was proposed by Professor David l mills of the United States in 1958, which is recognized as the earliest protocol for clock synchronization [5]. However, the clock synchronization accuracy of the protocol is poor, and it is difficult to meet some high requirements for clock synchronization between 1 and 50 ms. Since then, the IEEE1588 protocol, namely PTP (Precision Time Protocol), can achieve higher clock synchronization accuracy than NTP [6]. In 2002, IEEE officially approved the protocol. IEEE1588 has gained worldwide attention due to its technical advantages of sub microsecond time synchronization accuracy. In November 2005, the IEEE802.1AVB working group was established, and the IEEE802.1AS (generalized precision time protocol, gPTP) protocol was released in 2011. IEEE802.1AS protocol is improved on the basis of IEEE1588V2 protocol. The mechanism of two-step delay measurement is adopted to unify the type of clock [7]. In November 2012, the IEEE 802.1 Working Group officially renamed AVB as TSN (time sensitive network). In TSN standard, IEEE 802.1AS [8] provides global accurate time synchronization.

3. Implementation Method

3.1 Analysis of the Combination of Service Interoperability and Clock Synchronization
In the process of realizing the interoperability between devices, clock synchronization is an important link. Because of the direct interoperability between power equipment, this mode can complete the functions required by the power system without passing through the master station, and only through the communication between the terminal devices. Obviously, this method requires the terminal equipment to have a high time accuracy, generally about 10 µs, and some may require 0.1 µs [9]. In
this paper, we need to establish a service interoperability system, build a model of power equipment based on this system, so that it has the ability of self description and the corresponding service interface, so as to realize the plug and play function of terminal equipment and call each other; at the same time, the power equipment service interoperability model is used to effectively improve the clock synchronization of terminal equipment through the interface between them. The key point is to ensure that the model service interface can meet the requirements of time synchronization in terms of information integrity and efficiency, as well as the improved clock synchronization algorithm.

3.2 Construction of Service Interoperability System
Interoperability interface is an open software service interface for terminal equipment or system. In order to ensure the universality, the interface design needs to follow certain specifications. Based on the consideration of software requirements, this paper uses microservice architecture to design interoperability interface architecture.

Microservice is a popular design style in the current system architecture. Its purpose is to build the function of the original independent system by splitting. These small services run in their own independent processes, and they can communicate and cooperate with each other [10]. A microservice can correspond to a device or a function module.

Interoperability interface microservices mainly include communication interfaces, business management components, data management components and event management components. Communication interfaces, which are used to receive interoperability requests from other terminals and send information; business management components are mainly used to process the terminal's own business logic; data management components are used to manage all kinds of data of the terminal; event management components manage the events generated by communication interface calls.

So how to inform other relevant microservice interfaces in the first time when there is data change, we can design communication interface based on publish subscribe mechanism. The device that needs to respond is the subscriber, and the device with data source is the publisher. The subscriber can subscribe through the interoperability interface, so that when the data changes, the subscriber can receive the data in real time Make further response to achieve interoperability.

3.3 Clock Synchronization Method Based on Service Interoperability
After the establishment of service interoperability system, this method will establish a good interoperability model, deployed to time sensitive network (TSN), so as to meet the call frequency of high time precision. The clock synchronization method is improved based on TSN IEEE802.1AS, which adopts generalized precision time protocol (gPTP). In the TSN time sensitive network, the IEEE802.1AS protocol is equivalent to the application of the TSN scheduling algorithm. The procedure of the method is as follows:

The first step is to select the master clock of the network. A time aware network consists of some interconnected time sensing systems supporting gPTP. The gPTP model is shown in Figure 1.
In the process of synchronization, the upper level clock exchanges synchronization messages with the next level clock, so as to synchronize the next level clock. Finally, all the clocks can be synchronized with the best master clock. The master clock in a synchronous network can be determined by the best master clock algorithm (BMCA) [11] or by human configuration.

The second step is to measure the path delay. When gPTP message is transmitted between adjacent devices, the transmission path and reading information will take a certain time. The sync message is used to synchronize each time aware system with the master clock. Each time sensing system receives and sends sync messages step by step in time, so as to keep clock synchronization. The time synchronization information contained in the sync message includes the exact original timestamp, which is the timestamp when the master clock initiates the sync message.

Path delay measurement is to measure the delay time of information exchange between the current time sensing system $i$ and the adjacent time sensing system $i-1$. When the time sensing system receives the sync message, the message delivery process diagram is shown in Figure 2, and the specific process is as follows:

At $t_1$, time sensing system $i$ sends delay request message $delay\_req$ to $i-1$ and record the timestamp; At $t_2$, the time sensing system $i-1$ receives a $delay\_req$ message; At $t_3$, time sensing system $i-1$ sends out delay$_\_resp$ message with a timestamp; At $t_4$, the time sensing system $i$ receives a $delay\_resp$ message with a timestamp.

Therefore, when the message exchange is completed, four timestamps are recorded by the two time sensing systems. The propagation delay $D_i$ can be calculated by the following formula:

$$D_i = \frac{(t_4 - t_3) + (t_2 - t_1)}{2} = \frac{(t_4 - t_1) - (t_3 - t_2)}{2}$$

The third step is to compensate the master-slave clock frequency. The frequency difference between master clock and slave clock will lead to clock synchronization error. The main method to solve this problem is to use frequency compensation algorithm.

We can calculate the frequency ratio coefficient $r_i$, which is the ratio of the master clock frequency to the local clock frequency in the current time sensing system. In the process of calculation, the frequency compensation of two adjacent sensing systems should also be considered. The formula is as follows:

$$r_i = r_{i-1} \times nr_i$$
Where \( r_{i-1} \) is the ratio coefficient contained in the recently received sync message, and \( n_{ri} \) is the adjacency ratio coefficient, that is, the ratio coefficient of the nearest time sensing system \( i-1 \). Based on this proportional coefficient, we can obtain an improved formula for calculating propagation delay:

\[
D_i = \frac{(t_4 - t_1) - n_{ri} \times (t_3 - t_2)}{2}
\]

Finally, time synchronization is completed. The following Figure 3 shows the principle of time synchronization.

![Figure 3. Principle of time synchronization](image)

The correction domain \( C_i \) is calculated, which reflects the time taken by the sync message from the master clock to the time sensing system \( i \). It represents the sum of the time consumed in the propagation process and the time spent in the time aware system. Each time aware system will update this value. The formula is as follows:

\[
C_i = C_{i-1} + D_{i-1} - (t_i^s - t_i^r) r_i
\]

\( C_{i-1} \) is the correction range of the last sync message, and \( D_{i-1} \) is the propagation delay of the system at the current time. According to the time synchronization information contained in the sync information, the local clock of the time sensing system can be corrected to synchronize with the master clock. Assuming the best master clock function \( GM(t) \), when the best master clock is \( t \) at its local time, the clock of time sensing system \( i \) is \( t_Ri \), then the time after synchronization is:

\[
GM(t_i^R) = O + C_{i-1} + D_{i-1}
\]

At the same time, this method is compatible with the standard time synchronization protocol, and it can effectively compensate the time synchronization error.

### 3.4 How to Apply in Power System

In today's power system, the connection of different technologies will also cause interoperability problems. Then, how to apply the methods described in 3.2 and 3.3 in the power system. First of all, the idea of OPC UA standard can be introduced, because the interoperability and compatibility of OPC UA standard have been unanimously recognized in the industry. At the same time, OPC UA also supports the publish and subscribe mode.

The first step is to decompose and abstract the functions of the terminal equipment. The specific method is to analyze and sort out the functions of the distribution terminal and the data required by various functions according to the specific application characteristics of the distribution automation system and the distribution terminal; and then, to establish the OPC UA standard information model, unified data model modeling of distribution automation terminal, physical equipment division according to different functions, and corresponding the sorted terminal data to corresponding nodes. The method of selecting nodes and data is as follows: firstly, select the node according to the function,
then judge whether the node meets the functional requirements of the equipment, if it meets, select the node; if not, it needs to create a new node according to the standard and according to the demand. The next step is to determine whether the data in the logical node can meet the functional requirements of the terminal. If not, new data needs to be created. After the information model is established, the corresponding abstract service interface (information exchange model) should be established to exchange data within the information model, and each model should be encapsulated into microservices. Finally, the established data model and information exchange model are deployed to the network to realize the various functions of the terminal equipment.

After that, based on the established service model interface, the interoperability and data exchange between devices can be realized. At the same time, according to the above clock synchronization method based on service interoperability, the time synchronization in the process of equipment interoperability can be ensured.

### 4. Experiment

In this paper, the accuracy of time synchronization is evaluated by experiments on simulated data sets. The experimental methods are as follows: the two clock synchronization systems are directly connected through the network cable, and one is identified as the master clock and the other is the slave clock. When the synchronization of the slave clock and the master clock is completed, the difference between the time to be adjusted by the slave and the current time recorded by itself (absolute value, unit: ns) is output, and the synchronization frequency is set as follows 1 second, record 50 times. Table 1 shows the experimental results of clock synchronization system. After drawing the broken line diagram, it is shown in Figure 4 that the difference is concentrated in 150 ~ 450ns, the minimum value is 159ns, the maximum value is 448ns, and the average value is 302ns. The application standard can be reached.

The experimental environment of the clock synchronization system is windows10 operating system, the programming language is java1.8, the processor is Intel i7 8 core, and the memory is 8GB.

| number | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  |
|--------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| deviation | 362 | 384 | 325 | 167 | 448 | 269 | 159 | 362 | 365 | 165 |
| number | 11  | 12  | 13  | 14  | 15  | 16  | 17  | 18  | 19  | 20  |
| deviation | 258 | 379 | 287 | 284 | 359 | 420 | 265 | 287 | 164 | 337 |
| number | 21  | 22  | 23  | 24  | 25  | 26  | 27  | 28  | 29  | 30  |
| deviation | 265 | 264 | 174 | 235 | 278 | 269 | 303 | 169 | 333 | 236 |
| number | 31  | 32  | 33  | 34  | 35  | 36  | 37  | 38  | 39  | 40  |
| deviation | 364 | 256 | 268 | 266 | 387 | 368 | 268 | 346 | 288 | 345 |
| number | 41  | 42  | 43  | 44  | 45  | 46  | 47  | 48  | 49  | 50  |
| deviation | 400 | 326 | 401 | 298 | 255 | 399 | 445 | 268 | 197 | 362 |

**Figure 4. Clock deviation statistics graph**
5. Conclusion
This paper first summarizes the current research status of service interoperability and clock synchronization technology at home and abroad, and obtains the research significance and method of the combination of the two; and analyzes the application value of the method in the power system, and puts forward the application mode; finally, the method is verified by the experimental data, and concludes that the method has certain practicability.

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