A Time Service Improvement Scheme for Clock System of Nuclear Power Plant

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Abstract: This paper aims to research the necessity and specific methods to improve the time service of clock system of nuclear power plant. By researching and analyzing the current condition of the whole-plant clock system time service scheme, it propose an improvement scheme of time service system in the aspect of redundancy back-up, system networking, maintenance convenience, and power supply optimization. The research of this paper explores an efficient method to improve time service of clock system and increase reliability. It can provide guidance to the modification of in-service nuclear power plant clock system and the design of new nuclear power plant clock system.

Key words: Nuclear power plant, clock system, time service, improvement.

1. Introduction

The instrument & control (I&C) system and the electrical secondary system are the core of nuclear power plant control system. Only their normal and stable working can ensure the safe and stable working of nuclear power plant. At present, both instrument & control (I&C) system and the electrical secondary system need external time service signal to establish a uniform time synchronization network in the plant. The time of clock system maintain highly synchronization with GPS and Beidou system to ensure the normal working of the system [1], and it is a necessary technical method to facilitate the operating of the plant [2]. The external time service signal is provided by the clock system. Take CPR1000 nuclear power plant for instance, the clock system sets the main clock in XL building (Laboratory building) and sets remote modules in NI (Nuclear Island) and TB (main switchyard). It can provide time synchronization signals to the systems that need external time signals [3], [4]. However, the present scheme of clock system has the problems of low reliability, single point of failure and inconvenience of maintenance, etc.

This paper aims to thoroughly analyze the current time service scheme of the whole-plant clock system, and propose an improvement scheme of time service system to solve the current problems in the aspect of redundancy back-up, system networking, maintenance convenience, and power supply optimization. This improvement scheme can avoid the external time service signal failure and ensure the normal working of I&C system and electrical secondary system.

2. Current Condition of Time Service System

2.1. Overall Description

The clock system of nuclear power plant can generate standard time and frequency signals, it can provide accurate time synchronization signals such as IRIG-B, telegram, NTP [5] to I&C, relay protection, dispatching automation and other systems that need time synchronization signals. Clock system is composed of main clock subsystem, remote clock subsystem and power supply subsystem, etc.

2.2. Main Clock Subsystem

The main clock subsystem is the core of the clock system. Take CPR1000 nuclear power plant for instance, main clock subsystem is located in the communication room of XL building, which is composed by satellite signal antennas, satellite reference source and time service modules. There are two GPS/Beidou dual-mode satellites [6]-[8] signal antennas at the roof of XL building. The two ways of satellite signals are sent to a satellite reference source respectively. Then time signals are sent to time service modules from satellite reference source to transform into time service signals which downstream systems need. There are interfaces between main clock subsystem and remote clock subsystems to ensure the synchronization between main and remote clock subsystems. Meanwhile, the main clock system itself can also directly provide time service signal to downstream systems through time service module.

2.3. Remote Clock Subsystem

In consideration of the convenience and networking rationality of time service to downstream I&C system and electrical secondary system, we commonly set a remote clock subsystem in NI communication room and TB main switchyard communication room respectively. Remote clock subsystem is mainly composed by time service modules. These time service modules are actually the same equipments with those in main clock subsystem. You can simply consider that the remote clock subsystem is the main clock subsystem without satellite signal antennas, satellite reference source. The remote clock subsystems are connected with the main clock subsystem in XL through optical fiber in order to keep synchronization. Remote clock subsystems are also an important part of clock system, because most of the time service signals to downstream I&C system and electrical secondary system are sent out directly by remote clock subsystems, while the signals sent by main clock subsystem are only a small part.

2.4. Power Supply

The main clock subsystem and remote clock subsystems are powered by UPS in the communication room where they are located. The UPS equipments are also used by other communication systems such as telephone and computer network systems in the communication room. It is a shared power supply system, whose back-up time is 2 hours. When the input of UPS is interrupted, the back-up battery of the UPS will turn into operation and supply the clock system electricity for 2 hours. But considering the importance of clock system, a back-up time of 2 hours may not be enough, and we should take measures to extend this back-up time.

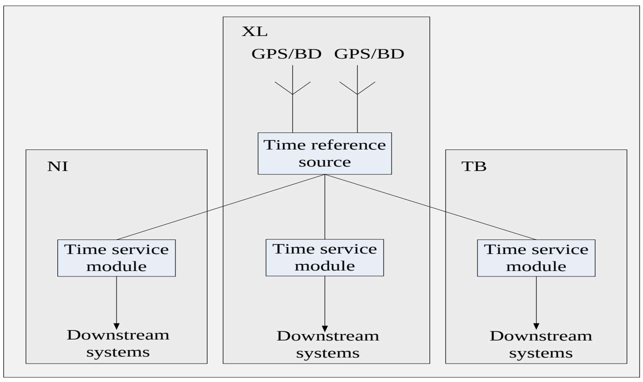

Fig. 1. Current system diagram.

2.5. System Diagram

The current system diagram is shown in Fig. 1. We can see that the scheme from the reference plant is too old, we must improve the scheme in many different aspects to increase reliability and avoid failure of clock system.

3. Improvement of Time Service System

3.1. Redundancy and Back-up

Looking into the current scheme of time service system, we can see that the idea of redundancy and back-up already exists. For example, the setting of two GPS/Beidou satellite signal antennas gives the satellite reference source two-way of satellite signals input, even one antenna is down, and the other antenna will take the place of it automatically. But after thoroughly analysis, the redundancy and back-up of current scheme are not enough. Although there are two GPS/Beidou satellite signal antennas, these antennas are connected into only one satellite reference source. Once the satellite reference source is down, the time source of the whole clock system is lost. It is a serious single point of failure and becomes an hidden danger, we must work out a method to eliminate it.

So when we research on improvement, the first step coming into our mind is to add one satellite reference source and the antennas are connected to each satellite reference source respectively. This method can be easily thought out, it also comes out very naturally. It can solve the single point of failure problem and increase redundancy. The next question is whether the time service module needs to back-up. The answer is negative when only consider redundancy. The downstream system has only one external time service interface, and it is difficult for the downstream systems to increase one time service interface. So even the number of upstream time service module increases to two, these two ways of time service signals cannot send to downstream system simultaneously. If we want to equip two same time service modules, the only way to solve the problem is that the clock system itself can automatically switch the two signals into one signal. But regretfully, the equipments of clock system nowadays are not advanced enough to realize this function. So, based on the current equipment condition of downstream system and clock system, we do not need to add time service module for the purpose of redundancy. However, we do need to add time service module for other purpose, which we will discuss later.

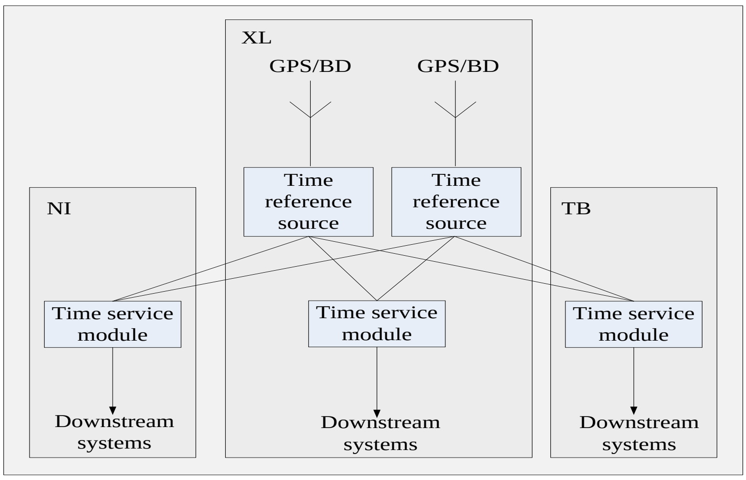

Fig. 2. System diagram after Redundancy and Back-up.

3.2. Network Optimization

In previous section we have discussed the improvement scheme of redundancy, in this section, we will discuss optimization in the aspect of system networking. As shown in Fig. 2, although we set two antennas and two satellite reference source, but we can see that these two sets of back-up equipments are actually in the same room of the same building. Once the communication room is down due to earthquake, flood, power supply lost or other reasons, even if we have two back-up equipments, we may still lost time source. In this aspect, the single point of failure still exists.

Moreover, from the aspect of construction sequence of different buildings, the finish time of TB building is earlier than XL building. So before XL building finishes, the remote clock subsystem in TB cannot receive accurate satellite signal from main clock subsystem, which would seriously affect the accuracy of time service signal. The downstream systems in TB are mainly electrical secondary systems such as relay protection, dispatching automation, etc. These systems are grid safety related. The grid company will not allow the nuclear power plant supply its electricity to the grid if the time synchronization signals of these systems are not ready.

For the reasons above, we can propose a network optimization scheme: Move one set of antenna and time reference source to TB. In this way, we separate the main clock subsystem into two parts, one in XL, one in TB. We can see that no equipment needs to be added. This is important because the cost of clock system will not increase. So the remote clock subsystem in TB upgrades into main clock subsystem. The time service modules in XL, TB, and NI simultaneously receive time signals simultaneously from XL and TB time reference sources. In this method, we completely solve the problem of single point failure by setting two main clocks in different places. Moving one set of time reference source into TB can make TB clock system independence. The time service modules do not need to rely on the source from XL, it can work normally by its own satellite antenna and time reference source. This can solve the problem that the downstream systems in TB need time service signals earlier than the accomplishment of XL time reference source. We can find the figure after Separating Main Clock in XL and TB in Fig. 3.

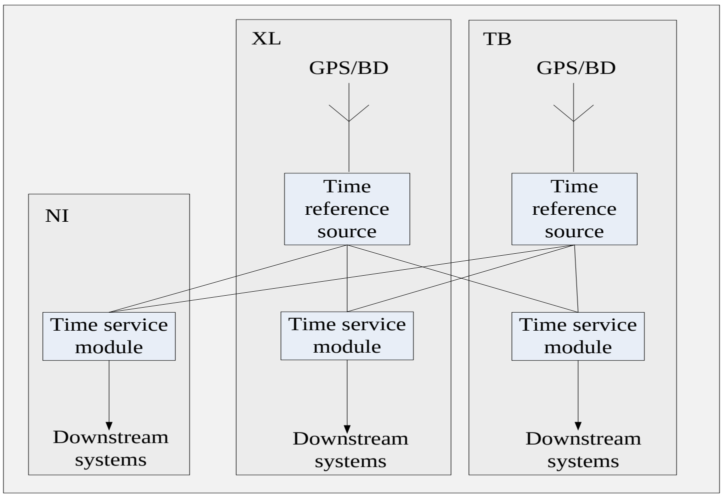

Fig. 3. System diagram after separating main clock.

When analyzing the downstream system time service requirements, we can discover that the number of equipments which need time services in CI (Conventional Island) is also very large. At present, these equipments get the time service signals directly from NI remote clock subsystem. If the downstream systems in CI get their time service signals from NI remote clock subsystem, there will be many cross-island cables from NI to CI, which increases the pressure of cable interface of NI. If the time service requirement in CI increases, additional signal cables must be increased, this is a rough task especially when the construction of the nuclear plant has finished.

So moreover, we can find the solution to increase one remote clock subsystem in CI. The time service modules in CI simultaneously receive time signals from XL and TB time reference sources. The downstream systems in CI get their time service signals from CI remote clock subsystem directly, which may significantly reduce the amount of cross-island cables and the network structure of time service system can be more clear. If the time service requirement in CI increases, additional cross-island signal cables need not be increased, it can get time service signals from CI remote clock directly. The cable laying work is much easier. We can find the figure after increasing CI remote clock in Fig. 4.

In previous section we have already discuss that it is not necessary to set back-up time service module, but in the aspect of networking optimization, we can still set several modules to avoid single point failure, one module for several systems, not for redundancy, but for network optimization. So even if one time service module is down, it would only affect the downstream systems the module supply, the other downstream systems would not be affected. In short, the key though is sharing the risk. How to set these increased time service module? It is a meaningful problem we will discuss it the section follows.

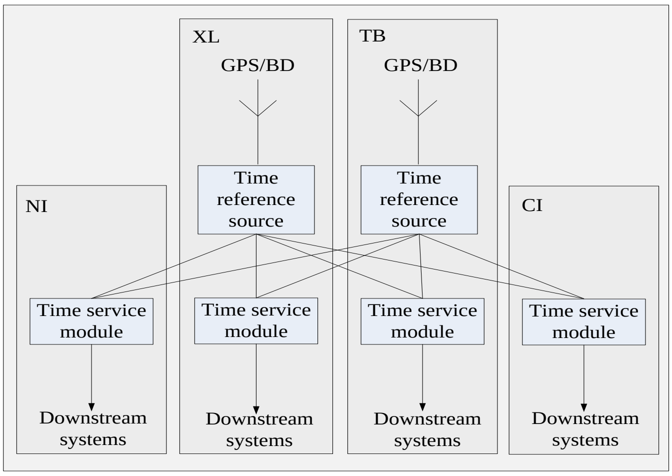

Fig. 4. System diagram after increasing CI remote clock.

3.3. Maintenance Convenience

According to the feedback of maintenance of reference station, it causes some inconvenience because all the downstream systems who need time service connect to one time service module. For example, one time service card in the module can supply 4 ways of signals, so this card is connected by 4 downstream systems. Once this card needs maintenance, the time service of 4 systems will be affected. Furthermore, if the time service module needs maintenance, all the systems will be affected. The external time service signals are very important to I&C systems and electrical secondary systems, so the negative influence of maintenance must be reduced as much as possible. Any interruption of external time service signal, however short it is, might cause unpredictable consequence.

In previous section, we have already discussed setting several time service modules instead of one to share the risk. This idea is undoubtedly correct, but the question is how many modules should be equipped and which principle can we follow. Equipping each downstream system with one module is the most “perfect” scheme, but the cost of this scheme is too large and it is obviously not necessary. Consider that most of the systems in nuclear power plant are set by unit, there are systems that belong to unit 1, unit 2 or unit 9, so we can equip the time service modules according to unit. We set several modules respectively for unit 1, 2, 9, and one time service card for one downstream system. In this way, one time service card maintenance only affect the downstream system it connected, there is no negative influence to other systems. Even one module maintenance only affects the systems of the corresponding unit. We can find the figure after separating unit in Fig. 5, notice that the need to separate unit only exist in NI and CI, where the downstream systems originally belong to unit. In NI, the downstream systems have the unit number of 1, 2 and 9. In CI, the downstream systems have the unit number of 1 and 2. However, in XL and TB, the downstream systems are all from unit 0, and do not need to separate the time service module by unit.

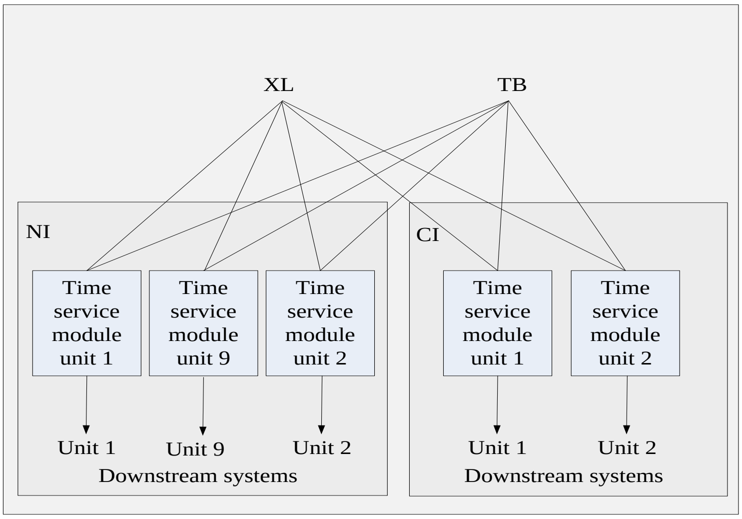

Fig. 5. System diagram after separating units.

3.4. Power Supply Optimization

We have discussed how to improve the clock system itself in the previous sections, but the power supply system is also the foundation of the normal working of clock system. In previous design scheme, we paid attention on the clock system itself and we were not so concerned with the power supply system, which is thought to be an auxiliary system. But in fact, however reliable the clock equipments are, it would be useless if the power supply is interrupted. According to the statistic data, 1/3 failures of communication systems are caused by power supply failure. So we cannot underestimate the importance of power supply reliability.

At present, the main clock system is powered by the UPS of communication room. As we have discussed in II(D), the UPS is also used by other communication systems such as telephone and computer network equipments. The power consumption of these equipments are very large, once the external power of UPS is interrupted, the battery of UPS will be exhausted very quickly, as short as may be two hours. So the back-up time of clock system is only two hours, which is not enough to satisfy the need of nuclear safety related systems under accident condition. In consideration that the power consumption of clock system itself is very small, we can equip clock system with a dedicated UPS, whose capacity is only 2KVA. This will not cause too much and occupy much more space, but it can extend the back-up time of clock system to 24 hours or more, which increase the reliability of power supply significantly. We can also give this small-scale UPS two-way electricity input, one from the UPS in the communication room, the other from the normal power of the building.

Meanwhile, at present, we only provide each clock equipment one way of power input. But nowadays, as the advancement of clock equipments, most main equipments of clock system support two-way power input. So for the clock equipments that have dual power input interface, we directly supply two power input to reduce the possibility of single point failure of power supply, although the upstream of UPS is already two-way input.

For the remote clock subsystem in NI and CI, we can increase a way of power input from diesel engine which already exists in NI. As a result, there is no need to increase a small-scale UPS because when the normal power is shut down, the diesel will turn into operation automatically takes over the power load. The back-up time can be as long as we wish if the diesel oil is enough.

We can find the figure for main clock after power supply optimization in Fig. 6.

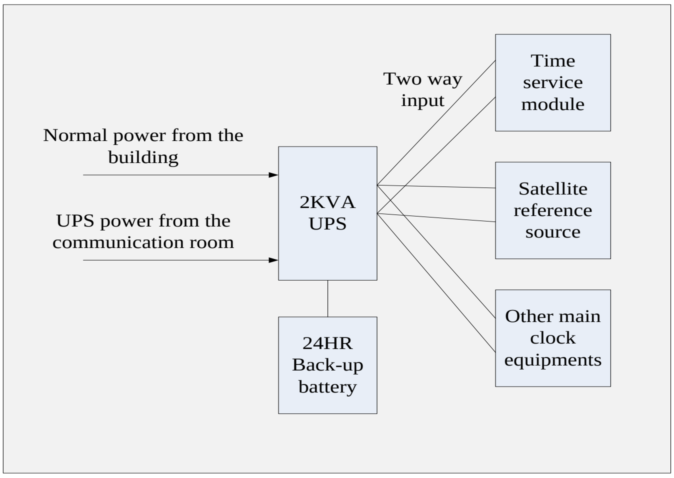

Fig. 6. System diagram of main clock after power supply optimization.

3.5. Final System Diagram

The final system diagram of improvement scheme is shown in Fig. 7.

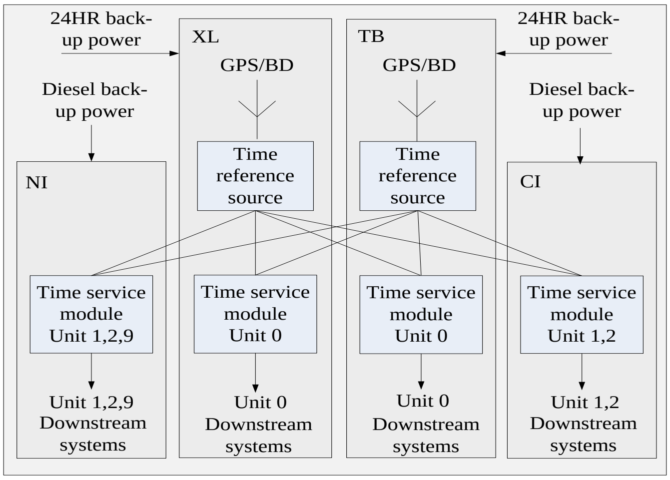

Fig. 7. Final improved system diagram.

4. Conclusion

This paper analyses the current scheme of time service of nuclear power plant clock system, and propose an improvement scheme of time service system to solve the current problems in the aspect of redundancy back-up, system networking, maintenance convenience, and power supply optimization. It also compares the improvement scheme with the current scheme. By means of the research of this paper, an improvement scheme of whole-plant clock system is proposed. This scheme has great significance on the building of clock system of nuclear power plant. It can reduce the probability of system failure and increase reliability to avoid the I&C and electrical system failure, which can save considerable maintenance costs. The scheme is not only suitable for CPR1000 project, but also suitable for AP1000, EPR, and ACPR1000+projects.

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