Application research of virtualization in life cycle management of nuclear power computers

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Abstract. At present, digital instrument control equipment and systems are widely used in nuclear power plants, in which computer is an important component of digital instrument control system. But the upgrading period of software and hardware system is very short. It is often faced with the shutdown of spare parts and the upgrade of software and hardware platform that can’t support the original application software, which brings great challenges to the life management of computer. This paper expounds the application status of computer in the digital instrument and control system of nuclear power, the characteristics of life management, obsolescence solutions and risks, and introduces the virtual server technology. The application cases of Demineralized Water Production System (hereafter called SDA) booster upgrading project in a nuclear power plant are summarized, and the application scope and limitations of virtualization obsolescence management strategy are summarized. The practice shows that virtual server technology can effectively solve the problem of computer life cycle management in some cases, which is conducive to reducing costs and increasing efficiency, and improving the competitiveness of nuclear power.

1. Introduction
At present, digital instrument control system has been widely used in emerging nuclear power plants, and traditional instrument control system has been upgraded to digital instrument control system in existing power plants. Compared with traditional analog system, digital systems are more complex and contain more components, such as computers, HMI, internal data bus, communication network, etc. Maintenance and repair of digital equipment is basically not feasible. These factors also make the digital instrument and control system or products have the characteristics of limited life or easy outdated. Therefore, it is very important to incorporate these digital devices into the life cycle management research and develop a comprehensive and exclusive strategy or plan for the obsolescence of digital instrument and control system and products. [1] Among them, computer equipment is an important part of digital instrument and control system, which undertakes the tasks of human-machine interface, data storage and calculation and analysis. For example, DCS, a large-scale digital instrument and control system which integrates 4C technologies such as computers, and computer is widely used in its upper computer systems such as operator stations, engineer stations, servers and so on. In the digital instrument and control system, the life of computer technology innovation is facing more complex life cycle management issues.

2. Characteristic of computer life management in nuclear power plant
Computer is widely used in digital instrument and control system of nuclear power plant, such as LEVEL2 layer of NC-DCS system. It mainly includes operator station host, gateway host, communication station host, configuration engineer station, configuration server, maintenance engineer station, backup station host, POP host, NI/CI/computing server, history server and LEVEL3 gateway and so on. Such as SDA, EPP, TCS, KRT, KIS and other PLC system workstations. It can be seen that nuclear power plants have a large number of computers. The obsolescence and upgrading of computers is facing many difficulties and challenges, the details are as follows:

2.1 Hardware and software incompatibility
With the rapid development of computer hardware equipment, it’s often faced with the problem of spare parts obsolescence, which needs to be upgraded with new hardware equipment. For the related operating system, application software and other software systems, there are no problems of failure and aging, but they are often incompatible with the upgraded hardware system. Moreover, software systems are upgraded in order to adapt the development of hardware and their own development needs. For example, the operating system may become obsolete in three years, while the distributed control system may become obsolete in six years. Therefore, when the hardware equipment is obsoleted and upgraded, it’s often accompanied by the upgraded of software system, but the procurement cost of software is generally high.

2.2 Different life cycle
The life cycle of computer hardware is usually 5 years, plus spare parts in stock, which can run for about 10 years. The hardware life of the lower computer is generally 10 years, plus spare parts in stock, which can run for about 15 years. For the upper computer system closely related to the lower computer, such as the engineer station, when upgrading it, the lower computer system has not reached the end of its life, considering the cost problem, generally do not upgraded the whole system. The compatibility between the upgraded upper computer system and the lower computer system needs to be tested and evaluated, which has a certain risk. Therefore, computer obsolescence has different life cycle between upper computer and lower computer, the node of obsolescence time is inconsistencies, and the risk of obsolescence is high.

For example, the NC-DCS system of nuclear power plant has been running for more than ten years since its design and debugging stage. The upper computer system has reached the end of its life. It is faced with the problems of lack of spare parts, shutdown of the manufacturer, slow response speed and high load. It is urgently needed to be obsoleted and upgraded. The preliminary general plan is that the computer hardware is upgraded from SUN Netra to x86 server, the system software version is upgraded, the operating system is upgraded Solaris from to Linux, and the logic/screen software is upgraded from V8.3/V4 to V8.5/V5. However, the lower computer has not yet reached the end of its life, considering the cost factor, it is impossible to upgrade the whole system for the time being. But at the end of the next machine life, the platform will be upgraded from AS5 to AS7. Compatibility problems caused by the obsolescence of the upper computer include: compatibility between the old version of engineering files and the new version of software system, compatibility between the compiled new version program and the old version of the lower computer, compatibility between the new version of the upper computer and the old version of the lower computer, compatibility between the upper computer system and the third party interface, etc. If the lower computer system is upgraded by stages and parts in the follow-up examination, the compatibility and construction solution of the system will be more complex and prominent.

2.3 Specialized software upgrade problems
In addition, some niche or special-purpose applications may face the situation that they have been phased out or not maintained and their sustainability cannot be guaranteed, so it is necessary to redesign the application files when upgrading the masterpiece.

In summary, the upgrading of computer equipment is inefficient, risky and costly. Computer elimination management is an unavoidable part of the technical life cycle of newly built and operated power plants. Through research and formulation of computer life cycle management plan, relevant
objectives can be achieved, such as maximizing service life, maximizing usability, maintaining safety, minimizing risk, minimizing cost or improving efficiency.

3. Solution to computer obsolescence in nuclear power plant

It is of great significance to study the types, risks, solutions and scope of application of computer obsolescence for maintaining the safe and reliable operation and cost control of nuclear power plants. Among them, the traditional obsolescence of computer has the follow solutions: equivalent replacement, selection of longer obsolescence cycle hardware, defensive procurement of spare parts, etc. [2]

For example, HP ProLiant DL580 G5, a commercial server, was originally used in the history services of a nuclear power plant. Because this type of server is a commercial type and has fast updating and long period of power plant design and construction, the equipment has been obsoleted shortly after the unit is put into operation normally. And the relevant electronic components have been shut down, when the field equipment is damaged, it will not be able to be repaired or replaced, which has a great impact on the system function. The nuclear power plant uses Linghua industrial server as equivalent replacement and purchases sufficient spare parts. This industrial server has longer spare parts supply capacity than commercial computer, and can improve spare parts supply capacity for seven years. However, these obsolescence solutions are only applicable to certain situations and will be subject to certain restrictions. For some special cases, such as the loss of industrial software authorization due to a long time, or the failure of a maintenance toll computer without permission to reinstall, the manufacturer refuses to provide support, even spare parts can’t be reinstalled at this time. In addition, the spare parts also has the same aging problems, the above-mentioned traditional solutions will not be able to solve.

This article will focus on the use of virtualization technology to solve the problem of computer obsolescence. Virtualization is through the simulation of hardware and software platforms, on which other software can be run. Virtualization, as a common practice in the field of information technology, is speeding up its entry into the digital instrument and control system to manage the software life cycle of the station directly.

4. Application research of virtual server in life cycle management of nuclear power plant

Virtualization server technology integrates the hardware resources of physical servers into logical resources, which virtual multiple independent virtual machines in one physical server, and allocates CPU, memory, disk, I/O card and other hardware resources to each virtual machine reasonably, thus saving hardware costs and improving resource utilization. With the wide application of virtualization technology, computer hardware manufacturers have begun to research on hardware. [3] With the continuous development of hardware-assisted virtualization technology, the operation of virtualization software is more agile and efficient.

Virtual server is a conventional design in IT industry, but it is seldom used in nuclear power digital control system. In this section, aiming at the enormous challenge of computer obsolescence and upgrading, a new idea and technical solution are introduced, taking the SDA upper computer upgrading project of a nuclear power plant as an application case.

4.1 The background of a nuclear power project

The SDA system of the nuclear power plant is a common system of the whole plant. The upper computer of its control system has been running for many years. The hardware of the system computer is aging, which often results in slow response and crash. Moreover, the main hardware of computer has been shut down, which seriously affects the reliability of the control system, so it’s urgent to upgrade the upper computer system. The original upper system frame diagram is shown in figure 1.
The operating system of upper computer is Windows XP, and the monitoring display software is InTouch 10.0. Windows XP has been obsoleted, and the operating system is Windows 7 generally, but the version of original industrial configuration software is low (InTouch 10.0), which does not support windows 7 system. Therefore, if the traditional upgrading solution is adopted, while upgrading the computer hardware, it is necessary to update the operating system to windows 7, update the monitoring display software to InTouch 10.6 or higher version, and update RS Logix5000 to version 16.0. The upgrading range is shown in the dashed line range.

4.2 Virtual server upgrade solution
This project chooses one physical server and two thin clients to build the upper computer network through two switching agencies. The system frame diagram is shown in Figure 2.

![Figure 1: The original upper system frame diagram](image)

![Figure 2: The frame diagram of virtual server upgrade](image)
The virtual management software platform adopts Ware vSphere 6.0, and the physical server adopts hardware-assisted virtualization platform DELL Power Edge T series. This server uses Intel Xeon processor which supports virtualization to support the operation of virtualization software and make it run more smoothly. With modular design method, the main hardware is independent of each other, and disk, CPU, power module and memory are redundant configuration. When the server is free from failure, each hardware device handles the information by itself. If one of the hardware equipment fails, the system automatically transfers the data that the hardware equipment needs to process to redundant hardware equipment for processing, so as to ensure that there will be no outage when the equipment fails. After replacing the failed hardware, the system will return to the original operating state automatically.

Combining Figures 1 and 2, it can be seen that the upgrade plan is packaging the operating system and applications (industrial configuration software) in the original two computers, convert them into virtual machine files, and migrate them to the server platform seamlessly. Two virtual machines are running on one physical server, that is, two sets of operating systems and application software of the original engineer station and operator station. The thin client connects to the system through the switch and accesses the virtual machine in the server. Taking switch A as an example, the working mechanism of system signal flow is introduced as follows: thin client A calls the original operator station virtual machine, and the original operator station virtual machine returns relevant information to thin client A, as shown in solid line ①. The two virtual machines communicate with lower controller through the server and switch AA, as shown in solid line ②. The operator station virtual machine and the engineer station virtual machine communicate through the virtual switch inside the server, as shown in solid line ③.

After upgrade, the operator can not feel the difference between before and after the upgrade. The new system maintains all the monitoring functions of the original system. And because the main hardware of physical server is thermal redundancy, the operation of operator station and engineer station will not be affected when a hardware failure occurs, and the reliability of the system has been improved.

4.3 Comparison of virtualization and traditional solutions

Taking this project as an example, considering only the main factors, the traditional upgrading solution is compared with the virtual server solution. According to the foregoing, if adopting the traditional control solution, we need purchase two servers, two operating systems, two InTouch software and one RS logix5000 software. The comparison of the two solutions is shown in Table 1, and the detailed analysis is as follows.

- In the aspect of main hardware procurement, because of the low cost of thin client, the virtual server solution is slightly better. In addition, based on the main characteristics of virtual servers, the effect of Cost Reducing and Efficiency Increasing is more significant when the number of servers in the original system increases.
- In the aspect of main software procurement, because the procurement cost of application software is high relatively, the virtual server solution only needs purchase the virtual platform software, the cost is very low.
- In the aspect of upper computer life cycle, if virtualization solution is adopted in the last life cycle, the upgrade of the next life cycle will be low-cost and efficient, which also fully demonstrates the advantages of virtualization solution.

Through the above analysis and combining with the technical characteristics of virtual server, the following conclusions can be drawn:

- The more computer in the system, the greater the effect of cost reduction and efficiency increase.
- For computers adopting virtualization technology, the upgrade work at the next life cycle will become simple, cheap and efficient.
- It is also an excellent solution to the problems such as loss of application authorization and non-persistence of the special software.
In addition, the virtualization solution will keep the original operating system and running view, and reduce human risk. Therefore, the application advantages of virtual server technology in nuclear power plants can be summarized as follows: low cost, high efficiency and low human risk.

### Table 1 Comparison of traditional upgrade solution and virtual server upgrade solution.

| Items involved | Main hardware procurement | Main software procurement | Total cost | Next life cycle | Winning solution |
|----------------|---------------------------|---------------------------|------------|-----------------|------------------|
| Solution 1: traditional solution | Two servers (about 50 thousand) | Two system software Two InTouch10.6 One RS Logix5000 (about 330 thousand) | 380 thousand | Face the same problem | Solution 2 |
| Solution 1: virtualization solution | One server Two thin client (about 30 thousand) | One VMware vSphere 6.0 platform software (about 6 thousand) | 40 thousand | Substitute for physical servers |

5. **Applicability and limitation of virtualization server solution**

With the continuous improvement of virtual server technology, including better tools for backup, recovery and migration of data, computer hardware design more matching the operation of virtual machine. It is believed that the application of virtual server technology in nuclear power plants will be more and more, but virtualization strategy still has its applications and limitations.

5.1 **Applications**

The virtualization solution can be used to both old and new projects in nuclear power plant. For the old project, the whole operating system and application program on the obsolete server are migrated to the virtual environment through virtual technology, and the upgrade work becomes very simple. Taking the Daya Bay Nuclear power plant as an example, there are more than 20 servers of each unit at present, if using this technology, the cost will be saved by about 50%. If the virtual server solution is adopted in the new design system, the subsequent hardware upgrade and replacement will be a very simple thing, which greatly improves the maintainability of the system.

5.2 **Limitations**

When using virtualization solution, we should choose the computer hardware platform to support virtualization, and we need to train the maintenance worker of nuclear power plant to master the maintenance ability of this technology, the detailed description is as follows:

- Virtualized devices generally use workstations, servers and equipment with standard hardware-level interfaces supported by virtualization platform software. These standard hardware-level interfaces including Ethernet, RS232/485, USB, SATA and so on.
- The obtained virtualization platform software should support all specific hardware configurations and operating system versions.
- It should have the resources that can configure and manage a large number of parameters and configurations of virtualized software platforms, such as experienced maintenance worker list.

If the original hardware device or interface is retained in the system, the original system needs to be checked to confirm that the selected virtualization software platform supports all hardware functions. Before handing over users, it needs to be evaluated and tested. The following are specified:

- There are special hardware or interfaces in the original system environment, which are not supported by the virtualization software platform;
- The virtualization software platform should not interface with any system functions or have any impact on the system functions.
- It does not simply to guarantee the equivalence of underlying hardware and/or operating system configurations for virtualization. Hardware and/or operating system changes should be carefully evaluated and tested before debugging and handing over to users.

6. Conclusion

The application of computers in digital instrument and control systems of nuclear power plants in China is becoming more and more popular, while the research of computer life management is still in its infancy. With the rapid development of computer software and hardware technology, the speed of upgrading and transformation can’t catch up with the speed of software and hardware updating, which brings huge capital and manpower costs to the operators of nuclear power plants, and also brings certain safety and quality risks to the safe and reliable operation of nuclear power plants. Virtualization technology has innate advantages in cost reducing and efficiency increasing. It is also a recommended method of EPRI in the study of digital instrument management and obsolescence control of nuclear power plants. In this paper, through the application of virtualization strategy in the upgrade project of SDA control system in a nuclear power plant, the advantages of virtualization strategy are analyzed, and the applicability and limitations of virtualization strategy are briefly summarized. However, it is still necessary to study the application evaluation and testing of virtualization strategy in the future. However, with the continuous development of server virtual technology and real-time controller virtual technology, it is believed that there will be more and more applications in the field of nuclear power.

7. References

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