Basic Concepts of APR1400 MMIS Digital Twin using Virtualization Technology

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1. Introduction

Virtualization technology has been widely used in many kinds of applications. For example, VMware can make x86 Xenon server into a bunch of small virtual computing machines. Each one has one or more CPU(Central Processing Unit) cores and designated memory and storage. It is called server virtualization. Another virtualization technology is hardware platform emulation such as Hypervisor. It doesn't emulate CPU itself, but only the instruction sets of CPU. The hardware platform means CPU and associated peripherals such as mainboard bus, PS/2 keyboard and mouse, serial port and floppy disk. Based on the emulated hardware, we can run the specific RTOS(Real-time Operating System) and its applications. A RTOS is an operating system (OS) intended to serve real-time applications that process data as it comes in, typically without buffer delays. Processing time requirements (including any OS delay) are measured in tenths of seconds or shorter increments of time. A real-time system is a time bound system which has well defined fixed time constraints. [1]

APR1400 MMIS(Man-Machine Interface System) has two kinds of digital platforms for safety MMIS and non-safety MMIS systems. POSAFE-Q is there to develop each safety system based on safety grade RTOS. And OPERA-1400 is there to develop each non safety system based on another RTOS which is called VxWorks. It is designed for use in embedded systems requiring real-time, deterministic performance and, in many cases, safety and security certification, for industries, such as aerospace and defense, medical devices, industrial equipment, robotics, energy, transportation, network infrastructure, automotive, and consumer electronics. [2]

APR1400 MMIS is a FOAK(First of a kind) system. For SHN#1&2, there were many design changes during the preliminary operation tests. A lot of human resources and cost were paid for the design changes. Let's assume that there will be some requests of the system improvement on the site. To deal with them, designer and manufacturer will review the requests based on their own engineering systems. If they don't have the same system as the local site, their solutions should be validated in the local site systems. Unfortunately, our nuclear power plant should be run continuously until its scheduled shutdown. Therefore the validation test can't be performed instantly after the solutions are provided. That's the main reason why we should have digital twin of APR1400 MMIS. There is another reason to make digital twin. If a site engineer proposes a small modification of control logic diagram, how can we test it and apply it into the real system.

A digital twin is a digital replica of a living or non-living physical entity. Digital twin refers to a digital replica of potential and actual physical assets (physical twin), processes, people, places, systems and devices that can be used for various purposes. The digital representation provides both the elements and the dynamics of how an Internet of things device operates and lives throughout its life cycle. [3]

KHNP have proposed a R&D project recently and is moving forward to make the digital twin of APR1400. It consists of the followings: 1) basic elements development to make a virtualized MMIS having identical and equal architecture and performance for its original configuration, 2) development of virtualized APR1400 MMIS using the basic elements such as virtual PLC, virtual DCS, virtual I/O and virtual network in terms of SHN#1,2 and SKN#5,6 MMIS systems, 3) development of smart digital twin for APR1400 MMIS which have smart engineering tools for design, implement and operation/maintenance phase, smart monitoring tools for MMIS, virtual machines and physical computing resources and finally management tools for this digital twin, 4) development of plant simulators integrating with the virtualized MMIS based on the SHN#1,2 and SKN#5,6 full scope simulators and 5) merging physical MMIS cabinets and virtualized MMIS in order to validate each other and its sub parts.

This study represents basic concepts of the R&D project and the overviews of the expected results in terms of virtualizations and how to integrate them.

2. Methods and Results

2.1 Objectives of the project

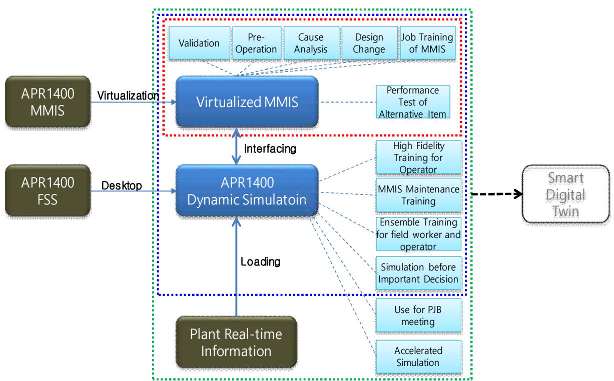

Fig. 1. Various possible applications of APR1400 MMIS

digital twin

To make better digital twin of a specific system, more accurate simulation is needed as a main engine. In this point, virtualized MMIS can be one of the best approach to develop a digital twin of MMIS. Using the virtualized MMIS and plant dynamic simulation, there can be many kinds of applications for operator, maintainer and engineer in the power plant. Above applications turn into top level requirements of smart digital twin of our R&D project.

Virtualized MMIS makes us enable to do various applications such as real MMIS validation and its preliminary operation, finding out cause of facility problems, test bed for design change ideas and job training for MMIS staffs as well as performance test of alternative items for new supply chain products.

If we use the virtualized MMIS and full scope simulation together, more accurate behavior can be provided to the plant operator. And ensemble HFE validation with local MMIS workers and MCR operators can be performed. Every one of this validation has his or her own systems not limited to the MCR display but included with local MMIS panels or cabinets.

We will expand our digital twin interfacing with plant real-time information system in order to maximize its applicability such as PJB meeting, important decision making and expecting abnormal event. If accelerated application is possible, we can expect when a component or system is not working in the future. Currently, this acceleration simulation can be done with two time faster than normal speed.

In this architecture, we can add another applications inside the digital twins using a common information interface. In other words, our project product can be used as an incubator or test bed for not only MMIS R&D but also applicable areas such as artificial intelligence, new design of next MMIS and operation and maintenance support system development. Virtualization techniques should be used as a primitive tool in order to share our resource and facility with encapsulating the real system.

2.2 Development of Basic Elements of Virtualized MMIS

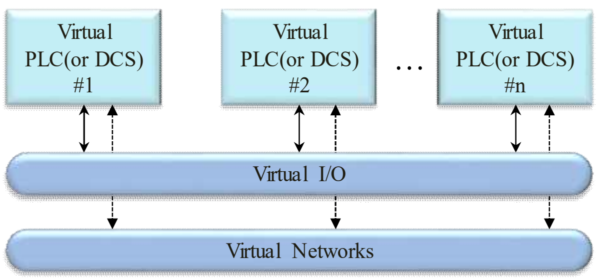

Fig. 2. Simple architecture of virtualized MMIS

To implement virtualized MMIS, we will develop virtual PLC for POSAFE-Q, virtual DCS for OPERA-1400, virtual I/O and virtual networks. These virtualizations are operated only in terms of software form like Fig. 1. The virtual PLC and DCS are different from two other things because they have its own specific hardware and configurations. In this project, the virtual I/O will be developed with an emulation of its values which means that I/O cables' characteristics are not simulated. The virtual networks will be implemented as the same as the real MMIS in SHN#1&2 and SKN#5&6 using the open source tools or commercial tools such as OpenStack, Nova and vSphere. In the case of safety systems, its network is implemented as tree or star structure. And in the case of non-safety systems, its network is implemented as normal communication structure.

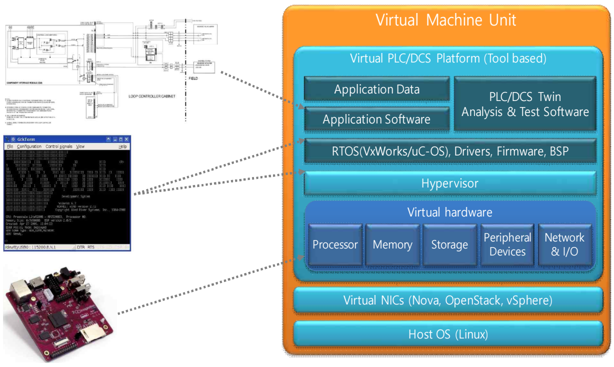

Fig. 3. Simple architecture of virtual PLC and DCS

One of the important requirements of the Virtual PLC and DCS is to run the same binary applications and logics as the site configurations without any modifications. To meet this requirement, their own RTOS can be operated on a virtualized hardware like Fig. 3. Virtual hardware is a key to implement virtual PLC and DCS. We will assign every virtual PLC and DCS into single VM(virtual machine) unit which has one CPU core and one NIC(network interface card) at least. Each VM has its own computing resources such as memory and storage. According to the recent x86 performance, we can deploy many VMs into one physical CPU like Fig. 4. Recent Intel Xenon CPU has more than 20 cores and it can be used more than 40 cores using Intel's virtualization technology.

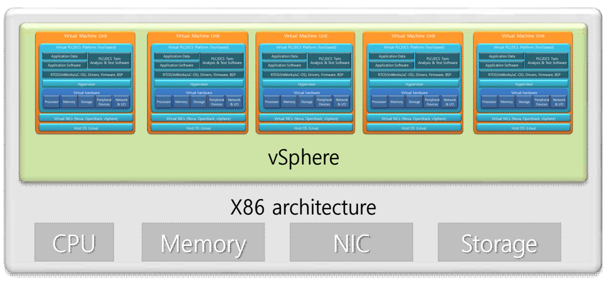

Fig. 4. Stacks of VMs on single x86 architecture

2.2 Integrated Development of Virtualized APR1400 MMIS

Mainly based on the virtual PLC, the safety system of APR1400 MMIS can be developed with connecting virtual PLCs with virtual I/Os and virtual networks reflecting the real ones. For example, real PPS(Plant protection system) has four channelized cabinets with dual processor modules which have inter-connection between themselves. To make it, we deploy eight virtual PLCs and divide them into four like channelized cabinets. And then each virtual PLC is connected to its own virtual I/O address and each divided group is connected to each other according to the real network configurations. We can make other MMIS systems for safety and non-safety as well as IPS(information processing system) of APR1400 MMIS as shown in Fig. 5. In addition to developing safety systems and non-safety systems, their own EWS(Engineering Workstation) systems should be integrated into the virtualized MMIS. Currently, to optimize the network efficiency and performance of each sub systems of APR1400 MMIS, a kind of blade servers is considered as a hardware platform for the virtualized MMIS.

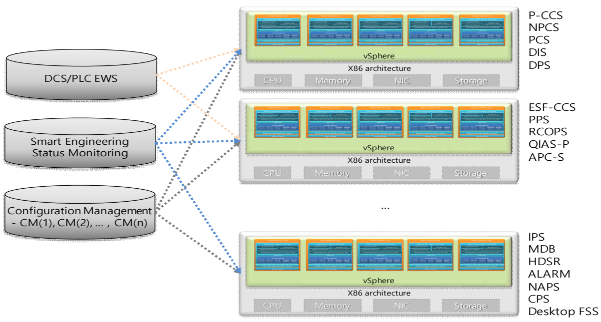

Fig. 5. Stacks of VMs on single x86 architecture

2.3 Development of Smart Digital Twin of APR1400 MMIS with Full Scope Desktop Simulator

The virtualized MMIS can be dealt with only the alternative of real physical MMIS. It is useful for prototyping or preliminary V&V before installing the real MMIS in the plant. To maximize its applications, FSS desktop simulator should be integrated with it and many other engineering applications should be developed and operated with it. Our digital twin can be divided into four functions and one virtualized MMIS as follows: 1) Digital Twin Management functions do configuration management of digital twin's software and contents, status monitor of physical and virtual computing resources and remote interfaces to each console, 2) Smart Engineering Tools provides the same applications as the real MMIS to operators and maintainers, various training programs and analysis tools to system engineers, 3) FSS desktop simulator for dynamic plant simulation and 4) Information Management for all the data to be dealt within the digital twin. Relations between them is represented in Fig. 6.

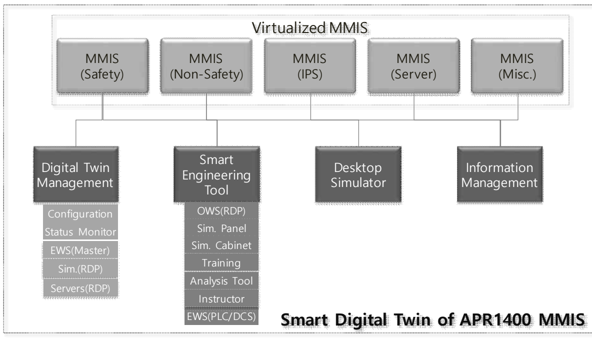

Fig. 6. Virtualized MMIS and its applications

Common interface for exchanging information between each other is implemented in the information management system. It has many mapping relations and database tables to support all the subsystems of digital twin. Considering the network performance, networks of digital twin can be divided into several sub architectures.

Desktop simulator is different from FSS in terms of whether it simulates the MMIS control logic inside or not. Developed desktop simulator doesn't have any MMIS control logics because they will be handled by virtualized MMIS. It should be implemented on the high performance VM unit.

All the subsystems except smart engineering tools are basic elements of the digital twin of APR1400 MMIS in terms of wide definition. One of the most important and valuable systems is the smart engineering tools because they are the same as our project's detailed objectives.

3. Conclusions

Digital twin provide the same behavior as the real system. Virtualization technology allows us to make the identical ones of the real systems on the software world. In this view point, recent digital MMIS is a good item for digital twin. Smart digital twin can be made of virtualized MMIS, desktop plant simulator like FSS and goal-oriented engineering applications. We expect that one blade server cabinet is enough to implement all the necessary systems for APR1400 MMIS digital twin. Therefore two products will be installed at SHN#1&2 and SKN#5&6 for plant engineering and training. One will be installed at KHNP CRI for cooperative work with other organization.

REFERENCES

[1] https://en.wikipedia.org/wiki/Real-time_operating_system
[2] https://en.wikipedia.org/wiki/VxWorks
[3] https://en.wikipedia.org/wiki/Digital_twin