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Applications of APR1400 MMIS Virtualization Simulator for the NPP's performance

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1. Introduction

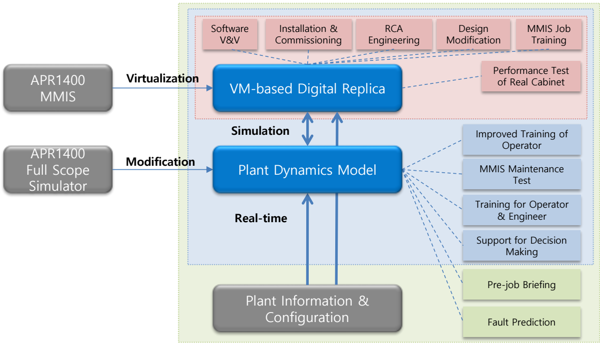

Fig. 1. Overview of APR1400 MMIS Virtualized Simulator

While the safety of a nuclear power plant is ensured, the activities to improve its performance should be allowed for. The plant performance has mainly four aspects such as stable and optimized costs, flexible operation, cogeneration, and environmental performance [1]. This paper proposes how a MMIS (Man Machine Interface System) virtualization simulator can be used for the plant's stable and optimized costs associated with the digital I&C. The localization of APR1400's MMIS was successfully developed as a first-of-a-kind in 2012, but it still doesn't have its own exclusive simulator. However, KHNP (Korea Hydro & Nuclear Power) proposed a R&D project in 2020 to develop the APR1400 MMIS virtualization simulator (is called shortly 'MMIS simulator' or 'virtualized MMIS') for supporting various engineering activities from design and construction phase to operation and maintenance phase. The project is on its way with domestic organizations. Fig. 1 shows the development directions of the project. The latest similar development was the application of a virtual Ovation system to ShinKori #3,4 full scope simulator (FSS). In that case, the virtual Ovation was used for covering only some parts of non-safety I&C systems and the rest of MMIS depends on the parts of the FSS. In the case of our MMIS virtualization simulator, it can cover both safety and non-safety I&C systems except for some 3rd party systems. There are some global vendors to provide virtual controllers in the world such as Siemens, Emerson, ABB, Framatome, and China's Nuclear Industry. They can be used for plant logic verification, I&C engineer & plant operator training, and plant logic development.

2. Development of APR1400 MMIS Virtualization Simulator

2.1 Features of MMIS virtualization simulator

There is a study on the use of virtual control systems for the plant logic verification [2]. In the study, virtual DCS (Distributed Control System) was developed in order to run the plant algorithm software and data source. There is a difference between the formats of the executable files for physical DCS and virtual DCS. It means the virtual DCS is based on function simulation methods. In that case, the virtual DCS can be limited to verify a plant logic in terms of function.

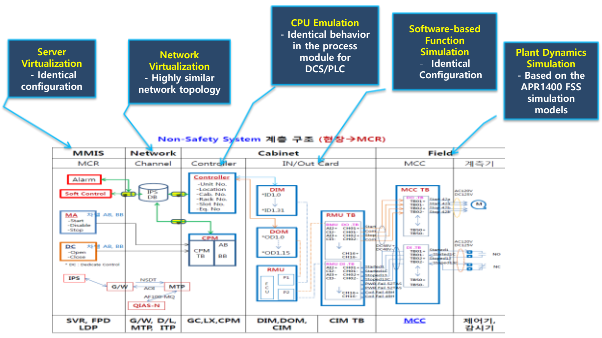

Fig. 2. Overview of APR1400 MMIS Virtualized Simulator

However, our MMIS simulator has mainly three components such as virtualized MMIS, plant dynamics model and its own MMIS engineering tools. The virtualized MMIS has been implemented with various levels of virtualization technologies from field sensors to MCR (Main Control Room) software systems as shown in Fig. 2. The following items have been successfully virtualized: 1) PLC (Programmable Logic Controller)/DCS's CPU and its peripheral parts, 2) MMIS network virtualization, 3) I/O & terminal block connection virtualization, and 4) integration with real MMIS cabinets. Based on these, the virtualized MMIS can be identically behaved to the real plant's MMIS. Some systems not to be covered by the virtualized MMIS are used with the APR1400 FSS's ones. Plant dynamics models for reactor, pumps, valves and etc. are simulated through APR1400 FSS simulation models. One of the important characteristics of the MMIS simulator is to create a virtualized MMIS for ShinHanul #1,2 or ShinKori #5,6 through SDA (software defined architecture) measures on a high performance computing machine. This SDA measures are implemented by the virtualized MMIS engineering tools. We call them 'Smart Engineering Tool'. It means we can create various structures of virtualized MMIS based on the SDA measures.

Fig. 3. Typical example of a PLC rack

2.2 Applications of MMIS virtualization simulator

According to its implementation characteristics, the real-time embedded OS (operating systems), their firmwares and binary softwares are running in the virtualized MMIS as identical as the real plant's MMIS. In addition, the network topology and non-software based connections such as I/O, fiber optic cables, and safety networks are also virtualized. The real engineering tools for PLC and DCS are also running in the virtualized MMIS. It means the various functions and tests in the real plant can be replaced with the ones in the virtualized MMIS such as follows. Some of them are difficult to perform in the real plant.

1) Design & Construction phase support

a) Quick prototype deployment of new equipment design: We can change the structure of a specific I&C system. If the system has originally five racks and a bunch of I/O modules in the real plant, we can make different deployment by adding or removing a rack with changed logics based on the MMIS virtualization technologies. This can be easily and quickly implemented.

b) Unit test and stability test of platform softwares and PC-based softwares: As the CPUs and peripheral parts of the processor modules for PLC and DCS are completely emulated, pCOS for PLC and VxWorks for DCS are identically running in a virtual machine. We can find out possible faults of pCOS, VxWorks and sub programs during the very long time period. PC-based softwares such as gateway program and data link servers can be also tested. When PLC or DCS platform is modified in terms of firmware, embedded OS itself and its associated binary tasks, function test and software V&V can be done.

c) Rack & Cabinet logic I/O test: A rack can be made from a virtual DCS or PLC with its own I/O and control agents. A cabinet is made from several racks and CIM, RMU and/or TB. Fig. 3 shows an example of a PLC rack. We can adjust all the values of each rack or cabinet's I/O points within Smart Engineering Tool like Fig. 3. Possible faults of wrong configuration in I/O points and wrong logics can be found through automated I/O test conditions.

d) Unit test of each system with a channel: If there are given inputs and expected outputs for several racks and cabinets of each system, a special GUI can be implemented for the unit test of each system. The different results between the expected outputs and the simulated outputs will be investigated for the unit test. If there is no difference, it represents that a system is well designed and made.

e) I&C systems integration test: System integration test can be done through time-based malfunctions, remote functions and override functions with plant dynamics models. Expected behavior of the plant can be identified.

Automated tests with combinatorial test conditions will help find possible faults within a short time rather than the real plant's test time. Reduced test time and increased reliability lead to improving the cost of the power plant.

Fig. 4. Typical example of Smart Engineering Tool for malfunction of the virtualized MMIS

2) Operation & Maintenance phase support

a) I&C equipment & network performance monitoring: The rack and cabinet's operating status, network load and transmitted data from a source point can be measured at any point in the virtualized MMIS. It helps the maintenance engineer better understand the behavior of the real MMIS. It is usually difficult to measure a network performance for the real plant because a special network analysis tool is necessary.

b) I&C equipment troubleshooting based on its malfunctions: All the components in the virtualized MMIS can be adjusted with an intended value. We call this, "a malfunction of a component". These malfunction are inserted at a specific time according to a test scenario. Various test scenarios can be constructed by Smart Engineering Tool. When we need to analyze the root cause of a trouble in the virtualized MMIS, we just insert possible causes through malfunction function. This malfunction was implemented as shown in the right part of Fig. 4.

c) Design modifications of platform softwares and logics including PC-based softwares: Before the platform softwares and plant control logics are modified, alternatives are tested in the virtualized MMIS from unit test to integration test as well as stability test.

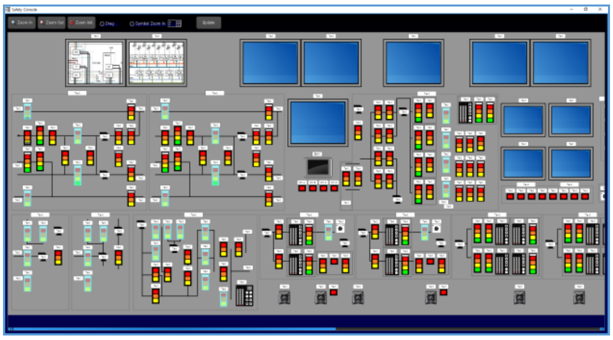

Fig. 5. Virtualized Safety Console

d) Engineer and Operator training facility with intended malfunctions: The virtualized MMIS offers various combinations of displays such as operator displays and MMIS cabinets at the same time. In the real plant, there are many cooperative tasks between MMIS engineer and MCR operator. Until now, it is very difficult to train these kinds of tasks for both staffs. The virtualized MMIS also offers the virtual safety console as same as the one in the MCR. Fig. 5 shows an example of the virtual safety console implemented for our project. All the signals from the switches are connected to the inputs of the associated controllers. And sub displays are implemented in each virtual machine. When user requests the display from the virtual safety console, the display will be provided at a specific position with controllable states.

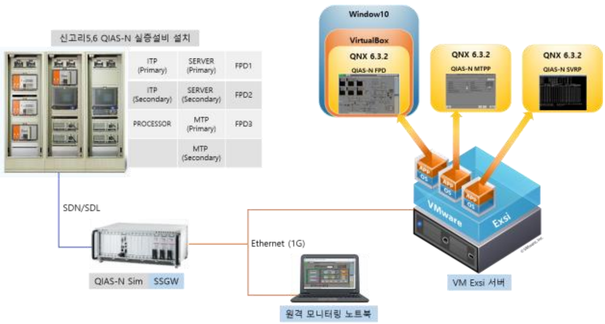

Fig. 6. Example of hybrid integration between QIAS-N real cabinets and virtual cabinets based on SSGW PC

e) Real equipment integration test: DCS or PLC cabinets can be integrated with the virtualized MMIS. DCS cabinets are connected on its own data highway based on the Ethernet cables. I/O data of the real DCS cabinets can be transferred from the virtualized MMIS through a specific physical tool. In the case of PLC cabinets, there is a small difference to connect the real PLC cabinets. That depends on the safety network for APR1400 MMIS such as SDN and SDL cables. The SDL is safety data link to connect each channel in a safety system. The SDN is safety data network under one channel. This connection is implemented through SSGW (SDN/SDL gateway) PC which has been developed for our project. For the example of QIAS-N system, Fig. 6 shows the real equipment integration using SSGW PC and virtualized QIAN-N. It is noted that data transfer between two cabinets was successful.

2.3 Future applications of MMIS virtualization simulator

1) Feasibility test for IoT (Internet of Things) devices and artificial intelligence: There is an available resource in a virtual machine in order to extend the functions of the virtual machine for artificial intelligence or any other computational functions. Many state-of-the-art techniques and technologies can be integrated into our virtualized MMIS. Virtual I/O parts and safety networks have been implemented based on the Ethernet connection, so various IoT devices can replace those parts. It means in the future virtual controllers are deployed through our components and its physical I/O parts based on IoT. It's a kind of hybrid control systems for the real plant.

2) Cloud-based virtual control system: According to the characteristics of virtual machines, all the virtualized MMIS components can be loaded into a private or public cloud system as long as they support our computational requirement.

3) Test bed for MMIS R&D of industries, universities and laboratories: Our virtualized MMIS and associated facilities including space and computational resources with the real plant information will be used for R&D test bed to Korean MMIS field stakeholders.

3. Conclusions

Virtualization technology allows us to make the identical ones of the real systems on the software world [3]. It is expected that the virtualized MMIS is used for various purposes from finding a fault to perform a difficult test and engineering analysis. Those activities can help improve the capability of the plant staffs, ensure the reliable operation of the I&C facilities in terms of plant performance.

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