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Development of a Prototype for the Digitalized Nuclear Power Plant’s Main Control Room

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요 약 본 우리나라 고리원전 1호기의 주제어실은 2007년에 부분 개선되었고 2013년에 완전 개량형화 될 예정이다. 부분 개선을 통해 원래의 아나로그 설비를 일부 대체하는 디지털 제어설비가 도입되었으며 안전변수표시 장치같이 단독으로 사용되던 전산시스템이 발전소 전산시스템에 통합되었다. 2015년에는 디지털화를 바탕으로 한 한국표준원전 주제어실의 개량이 예정되어 있으나 현장 엔지니어와 운전원들은 개량형 주제어실에 대해 호의적이지 않은 실정이다. 따라서 현장 운전원과 엔지니어들의 수용성을 제고하고 또한 사용자 인터페이스와 계측제어 구조를 평가하기 위한 표준형원전의 개량형 주제어실 모형이 개발되었으며 모형에는 운전원들의 업무 지원성을 향상시킬 수 있도록 화면이 다중 층으로 구성되며 층간에는 상황추종메뉴로 연결되어 있는 P&ID 베이스 디스플레이 시스템이 채택되었다. 이 시스템은 첫 번째 층에는 간략화 된 P&ID가 디스플레이 되고 계속해서 자세한 추가 정보를 디스플레이 할 수 있도록 고안하였다. 디지털 시스템의 신뢰성과 운전성을 고려한 한국표준원전 개량형 주제어실(MCR)의 최종형태가 제시되었으며 추가해서 운전에 영향을 미치지 않도록 발전소 정기보수 기간 중에 주제어실 현대화 작업을 수행할 수 있는 방안이 제시되었다.

Abstract Domestic Kori-1 MCR was partially modified in 2007 and will be renovated entirely in 2013. Digital devices partially replacing original analog devices have been introduced and standard alone computer systems such as SPDS have been integrated into the plant computer. Upgrading KSNP's MCR based on the ditalization is planned for 2015. However, the site engineers and operators are reluctant to the advanced systems. Therefore, a prototype for the KSNP's advanced MCR has been developed to increase the acceptance level of the operators and field engineers and also, to evaluate user interfaces and I&C architecture. For enhancing support of the operators' work, a P&ID based display system composed of multi-layers, which are linked through a context sensitive menu each other, has been adopted. The 1^{st} layer displays a simplified P&ID, the 2^{nd} layer control related diagrams such as controllers and logic diagrams, the 3^{rd} layer trends, etc. The end point view of MCR for KSNP is also suggested considering reliability and operability of the digital systems. Additionally, modernization strategies over the overhaul periods, that do not have much impact on operation and configuration efforts are suggested.

Key Words : MCR, Hybrid, P&ID based Display, Digital devices, Multi-layers, I&C Architecture

I. INTRODUCTION

Kori-1 has resumed power operation in 2008 following license renewal through a PSR (Periodic Safety Review). Many systems including MCR(Main Cotrol Room) were renovated during the PSR. Abbreviations of labels scattered in indicators or alarm

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tiles throughout the plant were rendered consistent. Indicators with a round curvature housing a moving needle are replaced with LED type, and the monitoring computer system was upgraded.

YG-3/4 will be 20 years old in 2015. Since I&C of the power plants is generally upgraded every 20 years due to advances in technology or obsolescence, YG-3/4 has become a target of I&C and MCR modernization. The initial proposal of I&C is to make wide use of digital networks and distributed controllers, MCR is considering a hybrid form comprised of traditional and advanced types.

While there have been considerable advances in information technology and human interfaces, the operators of the operating nuclear power plants are reluctant to accept advanced features.

The same response was observed in Kori-1. This could be a result of advanced MCR not providing as dramatic features as they expected. This paper adds new design features to facilitate operator's acceptance of the advanced MCR, and suggests an architecture for a MCR prototype, where consistent man-machine interfaces can be achieved.

Digital devices have powerful capability that can't be achieved in analog devices, including information integrated symbols. However, digital systems do bring some disadvantages as well. One of these is slow feedback at the control signal.

This can be removed by reducing the latent time of communication at each node or by proper hand shaking in the prototype.

Based on ergonomics, new concepts such as user-centered design, task-centered design, and ecological design are rapidly being introduced. Unfortunately, it is difficult even for human factor engineers to distinguish concepts. One practical limitation is that designers are not sufficiently familiar with nuclear operation to apply the principles. This paper explains how to derive a user-friendly interface from a P&ID (Piping and Instrument Diagram).

Although MCR modernization has been ongoing and related guidelines have been published since 1990, the actual modernization throughout world has not occurred to the extent that many expected. Northern European plants such as Ringhals and Oskashamn stay in the frontier. One of obstacles is long duration of plant shutdown for upgrading. This paper also introduces the modernization strategies utilizing successive overhaul periods without change in simulator, procedure, training, design validation, etc.

II. LESSONS FROM KORI-1

The PSR conducted in 2001 on Kori-1 MCR produced several HEDs (Human Engineering Discrepancy) as follows.

- Introduction of BISI (Bypassed and Inoperable System Indicator)
- Integration of SPDS (Safety Parameter Display System) into plant computer
- Consistent abbreviation throughout plant
- Potential reading errors in analog indicators
- Introduction of Kori-1 simulators

Even though these HEDs could be successively resolved, the plant owner decided to renovate the MCR on a large scale, because Kori-1 was the first nuclear power plant to come up for license renewal in Korea. They hoped a renovated Kori-1 would be recognized by nearby residents as a young plant. This project costs roughly 30 million dollars. Wolsung-1 will be the second nuclear plant to come up for license renewal in Korea, but a smaller scale upgrade is anticipated for its MCR compared to Kori-1.

The major design company in Korea became the main contractor of MCR modernization. Human factor engineers of utility participates in the project as independent reviewers even though the design company also employed human factor engineers.

The project was carried out according to

NUREG-0711 which defines 12 human factor elements applied to man machine interfaces. When design documents were written, they were reviewed by both Kori-1 operators and independent reviewers. Sometimes the operators and reviewers held different opinions on the design features. These conflicts were identified and resolved by the utility headquarters. Progress and design of Kori-1 was explained to the regulatory body when necessary.

Since the I&C architecture of Kori-1 was upgraded in 1998, no further budget on I&C upgrade was allocated. The old cable ducts, cables and control cabinets were reused as much as possible, and they were retained in the same physical positions as previously. Replacement of the old controllers with the distributed digital controllers and change of their positions were restricted. Furthermore, Kori-1 I&C engineers objected to the implementation of digital controllers because they did not want to incur any risk associated with new devices.

Fig.1 Overview of Kori-1 MCR

An overview of the modernized Kori-1 MCR is presented in Fig.1. The layout of the control panels corresponds with the previous MCR. The arrangement of indicators and switches are adjusted according to mass and energy flow. Because spatially dedicated BISI indicators are introduced, less important indicators are removed from the panels and entered in FPD (Flat Panel Displays). Both RO and TO consoles are enhanced with at least 3 FPDs. The mockup of upgraded MCR was built in KOPEC that designed it. Kori operators participated in design validation and verification of MCR through the mockup in 2009.

Fig.2 Legendary switch(Left), and J-Handler Right)

There are features that are not reflected in the renovated design. One is failure of replacing the J-handler with a legendary switch which has been widely used in Korean nuclear power plants. The reasons are that additional signals for disable status are needed, and that new controllers are needed to handle the signals from the changed devices. Furthermore, Kori-1 operators preferred the familiar switch over the legendary switch.

Integrating an alarm computer into the plant computer system was not achieved. The alarm computer on the operator desk shows the details of the alarm tile above the control panel. The alarm tile is not clearly visible at a distance. The alarm response procedure can be also opened with a click from the alarm computer. Advanced MCR integrates this feature into the plant computer system. Kori-1 operators preferred disintegration, because they wished to maintain Kori-1 in the same configuration as Kori-2. In addition, the different vendors of the two systems did not want to lose their roles.

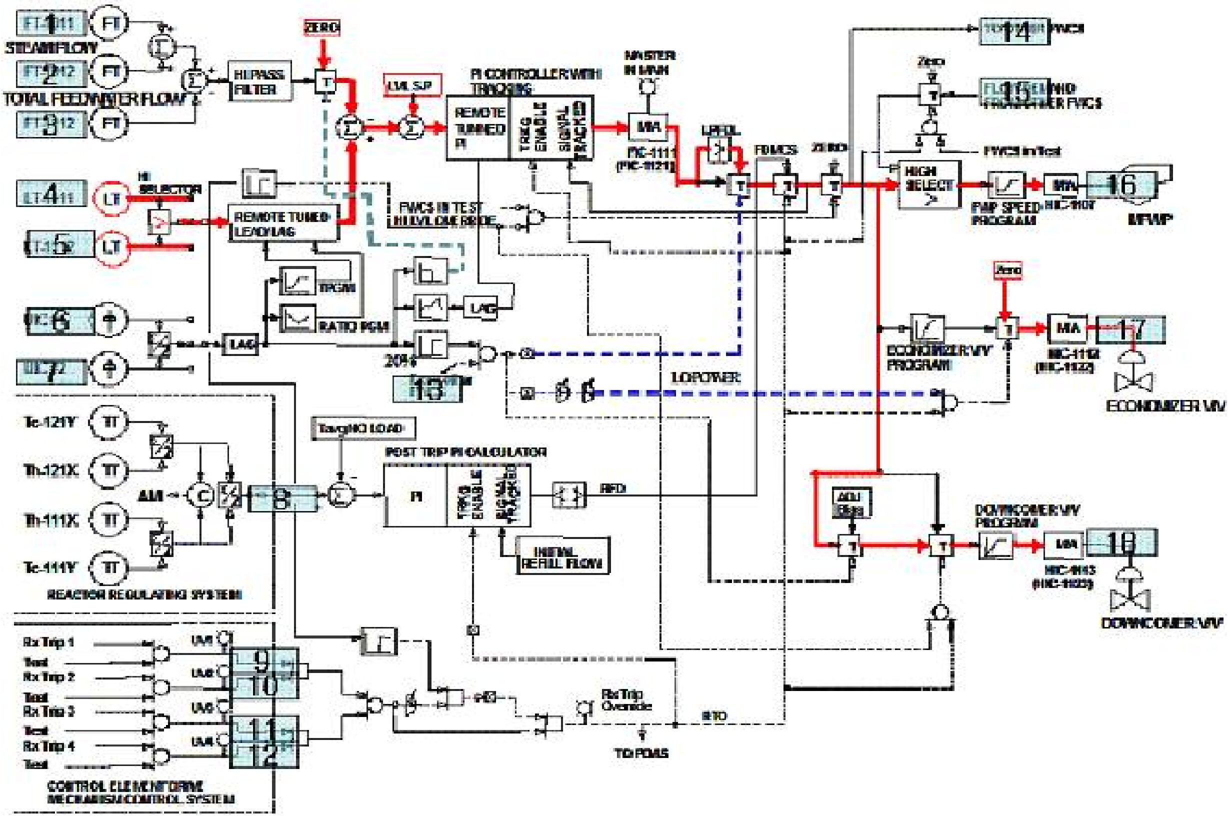

Fig. 5 SLCS Logic

Kori-1 MCR was partially upgraded in 2007 for license renewal, and will be entirely upgraded in 2013. The plant was initially scheduled to be shut down for 4 months for the work. Recently, however, Kori-1 engineers have been trying to shorten the shutdown period by preparing cables, equipment, and labeling in advance.

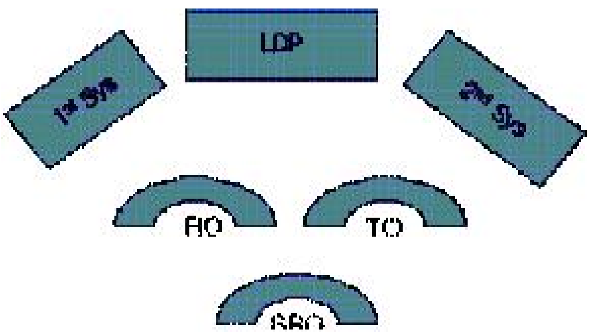

Fig.3 Layout of MCR

III. LESSONS FROM KSNP

YG-3/4 is a KSNP (Korean Standard Nuclear Plant). It will be 20 years old in 2015, and plans are in place to upgrade the plant with a digital I&C system. PLC and DCS will be utilized. The controllers are interconnected in communication networks. At the same time, MCR will be renovated. The project for YG-3/4 I&C architecture and MCR end-point view has been carried out for 2 years.

The layout of MCR is shown in Fig.3. The LDP is a large display panel that is driven by an electric device. The LDP shows the overall plant state including important valves and pumps. It also shares design characteristics with SinKori-3/4, which is under construction with an advanced MCR. RO, TO, and SRO consoles are equipped with FPDs. The display pages in the FPD are manually navigated to steer the plant. The 1st and 2nd pannels shown in Fig.3 are introduced as backup systems when digital display systems are unavailable. They provide the minimum necessary indicators and controllers.

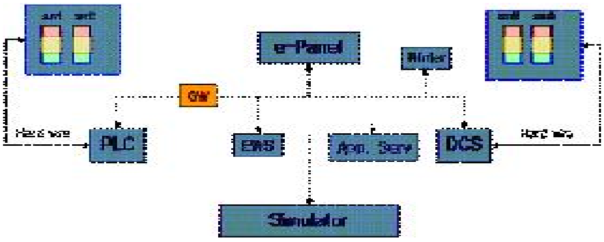

Fig.4 Prototype of YG-3/4 MCR

The prototype, schematically illustrated in Fig.4, of the above design was constructed. The PLC and DCS have been provided from the products of the KNICS (Korean Nuclear Instruments and Control System) project. The KSNP simulator runs on Windows operating system. The architecture of the control and monitoring system has been simplified without redundancy in order to meet budget constraints.

A DCS for controlling the steam generator level has been implemented in the prototype. Control logic has been edited in function block provided by Isagrapgh software tool. SG level, steam flow, feed flow, reactor power, and RCS temperature are fed from simulator to the DCS by reading internal memory of the simulator. Pump speed is calculated through the control logic and dispatched into e-Panels. The logic diagram of the SLCS (Steam Generator Level Cotrol System) is shown in Fig.5.

Digital networks have been gradually introduced to the Korean operating nuclear power plants. However, experience with these systems has not been as successful as initially expected. Several problems with digital communication occurred, resulting in replacement of digital networks with hard wires. Human errors with the digital systems have also occurred. When problems in digital systems occur, it is often difficult to find out the cause of the problem. Accordingly, the operator's trust in digital systems has weakened, and additional analog design features have been introduced. The final architecture thus becomes complicated to understand and repair while adding with no benefit in reliability. The best remedy for this is to increase the reliability of individual digital devices and to simplify their connections. This principle is applied in the prototype.

Generally, PLC is considered to be simpler than DCS, and is used for safety systems in the nuclear plants, whereas DCS is employed in for non-safety related systems. The isolation criteria between safety and non-safety are so strict that it is difficult to achieve a consistent man machine interface between safety and non-safety. Because DCS is becoming more reliable, however, it can be certified in terms of safety in the near future. Meanwhile PLC is expected to become more powerful in the future, and hence it can be used instead of DCS. The architecture presented in Fig.4 is designed to yield to obtain consistent user interfaces.

The feedback of a PID controller, such that illustrated in Fig.6 is important for proper actuation. When a control signal is issued into the network, the feedback from the actual component takes 2 ~3 seconds due to either loss of the control signal or delay in middle nodes. The slow response frustrated operators, and sometimes worsened transient state. These phenomena occurred in one of the simulators, and were resolved by tuning the communication protocol. The general remedy for this problem is to remove separate network layers such as information and control. Because recent communication protocols were validated formerly and have enough bandwidth when introduced in the market, it is not a good approach to add propriety communication lines to supplement them.

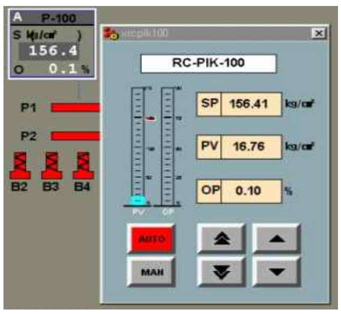

Fig.6 PID Controller

There are 3 types of MCR. The first is a traditional and physically dedicated MCR, the second is an advanced one based on a flat panel display, and the third is a combination of both, and is referred to as a hybrid type. Almost all new plants are designed according to the advanced type, where more information is available and maintenance is more convenient.

With respect to MCR modernization, the present operators are reluctant to accept the advanced MCR. They have already gained extensive experience with digital devices and flat panel devices for monitoring purposes over a long period. They complain that LED devices do not respond quickly, and are not large enough to read from a distance. Although, the current plant monitoring computer provides a limited number of process values, and its display design is not attractive comparison with recent graphic displays, they feel that the present MCR is sufficient for control and monitoring of the plant. This situation is similar to when customers face the situation of adopting a new operating system and must decide whether or not to upgrade.

For successful MCR modernization, more attractive displays and more powerful functionalities should be provided. Integrated information, advanced alarm processing and support for procedures are candidates with regard to the latter.

When a reactor trips, there is an avalanche of alarms, as evidenced in the TMI accident. Thus there are numerous techniques to reduce the number of alarms, such as alarm suppression. Another issue is the alarm state. The state is determined by process value and SART (Silence, Acknowledge, Reset, Test) buttons. Uljin operators have used another tag to indicate that proper actions are undertaken to recover the alarm.

For enhanced support, the operators' tasks should be analyzed broadly and thoroughly. As GPS (Global Positioning System) become accurate and economical, many information displays that use GPS in congestion with a geographical map have been commercially available. The same principle can be applied to the control and monitoring systems. This system can be called a P&ID based display. P&ID shows pipe lines, valves, pumps, sensors, transmitters, and controllers. Control logic and cable routings are not shown in the P&ID.

When a display is designed in view of ergonomics, it is referred to as user centered design or ecological design. Both describe the objective of user friendly design, not methodology. On the other hand, the P&ID based display is based on methodology fulfilling user friendly design.

Both Fig.7 and Fig.8 show how the P&ID based display is designed. The original P&ID shows pipes as well as physical positions of sensors, which are not major concerns for operation. The physical position becomes important only when a sensor is not functioning. The simplified display of Fig.7 shows the pipes for main energy and mass transfer without sensing lines.

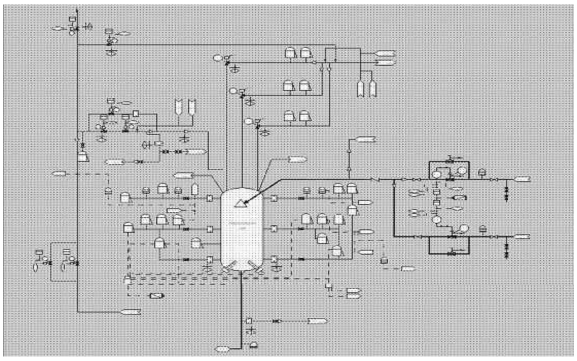

Fig.7 Original P&ID

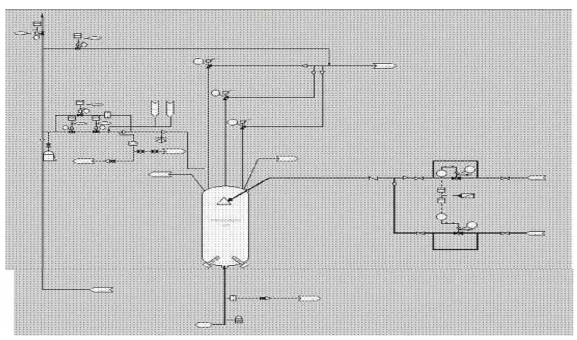

Fig.8 Simplified P&ID

The simplified P&ID is sufficient for normal monitoring of the systems. However, operators wish to control the devices, know the tagged devices, know the control logic, and know the physical position of sensors, alarm set points, etc. Thus the simplified picture is not adequate.

When a GPS and map are integrated, map based applications can be realized. The same principle can be applied to plant applications. Such applications are called P&ID based applications. The entry point of application begins with P&ID. The simplified P&ID is the first layer, a second layer is constructed for control related displays such as controllers or control logic diagrams, a third layer for trends, and a fourth for the position of sensors, etc. The layers can be accessible through a context sensitive menu pop-upped by clicking symbols on the first layer.

When there is one-to-one mapping between a pump and a switch, the simplified display shows only the pump, and when the pump is clicked, the switch appears. However, there are many-to-many mapping among process values to the controller in PID. As such it is not easy to determine whether the controller is shown in the simplified P&ID or not. If the controller is shown, numerous dotted lines appear. If the controller is not shown, the control loop is hidden at the first level from operators.

One advantage of digital symbols is flexibility. A process value as well as an alarm set point can be shown in one symbol. Validation status, and changing rate can be also integrated if needed. Fig.9 is a pump symbol of APR1400. a similar symbol will be used in the upgraded KSNP's MCR.

Fig.9 Integrated Digital Symbol

The integrated symbol requires set of attributes such as the current value, symbol name and type, and alarm status. The designer should determine when or where these attributes are derived and grouped in the route from a sensor to the FPD. The data from PLC or DCS are primitive and are not structured types. The data are grouped into a structured form for symbol display. In the prototype, the primitive data are structured in a database prior to being used in the symbol. When structured objects are stored in a database, it is easy to reuse them in other applications [1][2].

IV. MODERNIZATION STRATEGIES

Shortening the period of modernization is also important. Scheduling of I&C upgrade during overhaul period results in complicated project management. Occasionally a single overhaul can be allowed for I&C upgrade. Such an overhaul is not preferred, however, from a economical point of view as evidenced in Kori-1.

The modernization strategies of KSNP are mixtures of both types as illustrated in Fig.10. During the first overhaul period, non-safety I&C systems are replaced with DCS and communication networks. Analog devices in the MCR remain in the same place, and digital based devices in the MCR are upgraded with control capability. However, initiating control from the device is blocked. The present digital device is used to monitoring the plant. The second phase targets safety systems with the same principle as the non-safety systems. MCR is upgraded at the final stage, and the number of analog devices is reduced at this point, and digital devices are released to control the actuators.

The apparently same MCR is maintained from the 1st stage to the 2nd in this strategy, and thus operators do not require training at every stage. Furthermore, there is no need to change the simulator due to unchanged MCR. Whenever man-machine interfaces are changed, there are 12 elements that the utility must follow, in NUREG-0711[3]. These elements demand much effort and the results are reviewed by a regulatory body.

Even though the most dramatic change in the MCR is soft control through the FPD, its impact on operation is buffered though gradual introduction. Because operators become accustomed to control menu on the digital device from the 1st stage, control capability can be managed when it released in the final stage.

To maintain the apparently same MCR during the two I&C upgrades, where DCS and PLC replace the previous controllers, hard wired cables between the analog devices and both DCS and PLC are reconnected. These efforts involved in this approach are far less than those for the aforementioned the 12 elements.

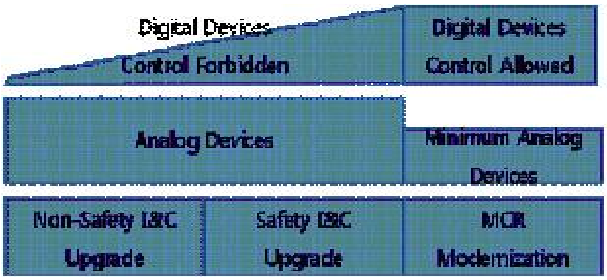

Fig.10 Modernization Strategy

V. CONCLUSION

Main control rooms of Korean nuclear power plants are supposed to be modernized in parallel with digital I&C. Operators and I&C engineers, however, are reluctant to the modernization. A prototype of MCR has been designed and developed to verify the advanced design features and user interfaces. The FWCS is implemented in KNICS PLC and DCS, which is connected with KSNP simulator. The prototype seems to increase acceptance of digital I&C.

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