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PLANT AVAILABILITY DESIGN ASPECTS OF KOREAN NEXT GENERATION REACTOR

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Abstract

The purpose of this paper is to describe the KNGR design concepts adopted for reducing forced outages and refueling outages, and current design changes, to assess their availability impacts compared to existing domestic nuclear power plants, and then to identify design directions for next design stage.

1. INTRODUCTION

The KNGR project is aimed at providing the standard design of an advanced pressurized water reactor by 2001. The development consists of three phases. During the first phase from 1992 to 1994, the selection of preliminary design concepts was made and the top-tier design requirements were developed [1]. To ensure these top-tier design goals, the Center for Advanced Reactor Development (CARD) has organized the plant level analysis group which views the top levels of design verification such as safety, economics, constructability, performance, and radiation protection of the plant in the basic design stage (phase II). As one of the plant level analysis topics, the plant performance is assured in terms of power production capability (i.e. plant availability) through the RAM program.

The availability of future nuclear power plants is generally targeted to accomplish at least an 87% average during plant lifetime. The availability of existing Korean PWRs has shown an increasing trend since commercial operation of the first nuclear power plant, Kori Unit 1 and has been approaching 87% during past a few years as shown in FIG. 1 [2]. So the availability target of KNGR is established higher as 90%.

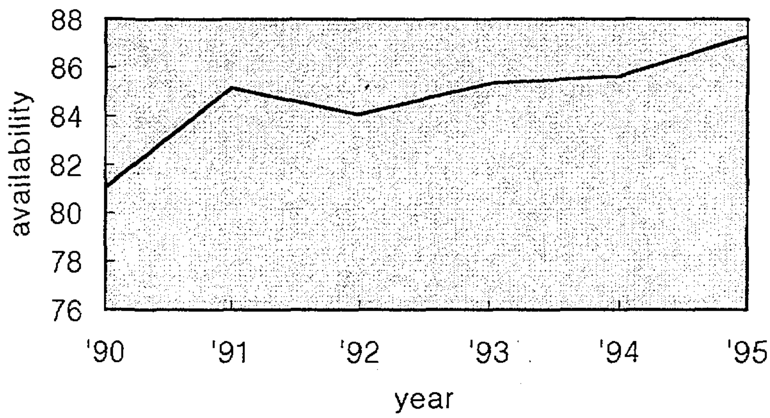

FIG. 1. Availability History of all Korean PWRs.

In order to achieve this target, it needs to improve design configuration and adopt new design feature. Overall plant availability is being assessed and its results are fed back into the design and reassessed. Availability assurance is implemented by repeating this process during the basic and the detail design stages. Each design stage has its unique feature to provide more input for availability assurance. These features are addressed in this paper.

2. FORCED OUTAGE

Forced outage is expected to be easier outage types than planned outage or extended outage type. Because existing domestic nuclear power plants have almost approached the KNGR targets during past a few years, which are;

- Trip frequency : less than 0.8 per year
- Forced outage: 2.4 days per year

2.1 Current design approach

At the basic design stage, the plant configuration is initially being settled to maximize availability, considering;

- design simplification
- amount of redundancy
- degree of diversity
- design of the support system infrastructure
- reliability and maintainability of individual components

Since the KNGR is being designed primarily based on the KSNP which has significant experience on the construction, startup and operation, it is expected to accomplish the forced outage targets. Therefore, the design is focused on the simplification to provide advantages to the economy of the KNGR by reducing the construction cost. Recent some design changes show these features well.

(a) Turbine building open cooling water system (TBOCWS)

The function of TBOCWS is to supply seawater to the turbine building closed cooling water system heat exchangers for heat removal. Seawater which is used as the source of cooling water and as a heat sink, is supplied by circulating water pumps in KNGR TBOCWS instead of TBOCW pumps as in KSNP. Thus, two 100%-capacity TBOCW pumps (TOP) are deleted compared to KSNP. This results in reducing plant unavailability as much as;

$$\Delta U = (\lambda_{TOP} \cdot \tau_{TOP})^2$$

where, λ is failure rate during a given period of time and τ is mean time to repair (MTTR).

Although the amount of the differential unavailability expected is not much large by itself, it contributes to increasing KNGR economics. Since it reduces construction and maintenance cost as well as unavailability.

(b) Main feedwater pumps

The FW system supplies feedwater from the deaerator storage tank to each of the two steam generators at the required pressure, temperature, and flow rate. The function of the system is to raise the pressure and temperature of the feedwater and to supply this preheated high-pressure water to the steam generators for conversion to steam. The system is also used to maintain proper water level in the steam generators during steady-state and transient operation.

The feedwater pump arrangement of KNGR consists of three parallel main feedwater pumps driven by variable speed steam turbine, and the parallel and identical feedwater booster pumps as shown in FIG. 2. A parallel startup feedwater pump is also provided for startup, shutdown and hot stand-by operation. All three main feedwater pumps are normally operating. The maximum capacity of each pump is 55% respectively.

The KSNP arrangement is two normally-operating pumps plus one spare pump. This arrangement also accomplish the objective of 100% power with one pump out and has the additional advantage that the pump can be run at their design point.

The KNGR arrangement requires the pumps to be run somewhat below their design point during normal three-pump operation so that the flow above design flow is not excessive during off-normal two-pump operation.

However, the KNGR arrangement, with three normally-operating pumps, is considered preferable because it provides a smoother transient following a pump trip and therefore lessens the risk of a plant trip.

The current KNGR main feedwater pump arrangement, furthermore, is being reviewed to study the feasibility of additional design change for improving reliability. One concept is to change pump drive type from steam turbine to adjustable speed motor (ASM) and the ASM driver is also used for driving main feedwater booster pump as shown in FIG. 3.

Considering that the maximum capacity of each main feedwater pump is 55%, equivalent unavailability is;

$$U(EQ) = U(100\%) + U(55\%)$$
$$= 3U_{LINE}^2 \times (1 - 0.55) + U_{LINE}^2 \times 0.55$$
$$U_{LINE} = \Sigma \lambda_i \cdot \tau_i$$

where, ***i*** is each component in one of three pump lines.

Since little operational data is available in the nuclear industry, quantification of above equation is possible by only a vendor's data at this time. Anyway, it is certainly a good design concept from an availability point of view that single ASM driver replaces two different types of drivers. So its adoption is soon to be decided after technical review on its reliability and maintainability together with some vendors.

If the ASM is adopted for KNGR, it is expected to bring another advantage. The concept is that main feedwater pump with the ASM driver can be used for startup instead of existing main feedwater startup pump.

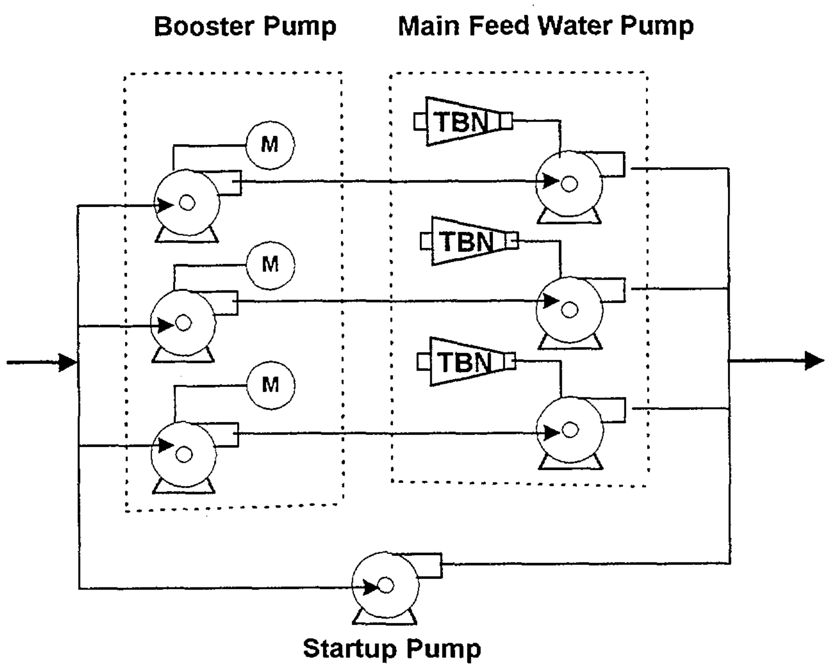

FIG. 2. Current Arrangement of Main Feedwater Pumps.

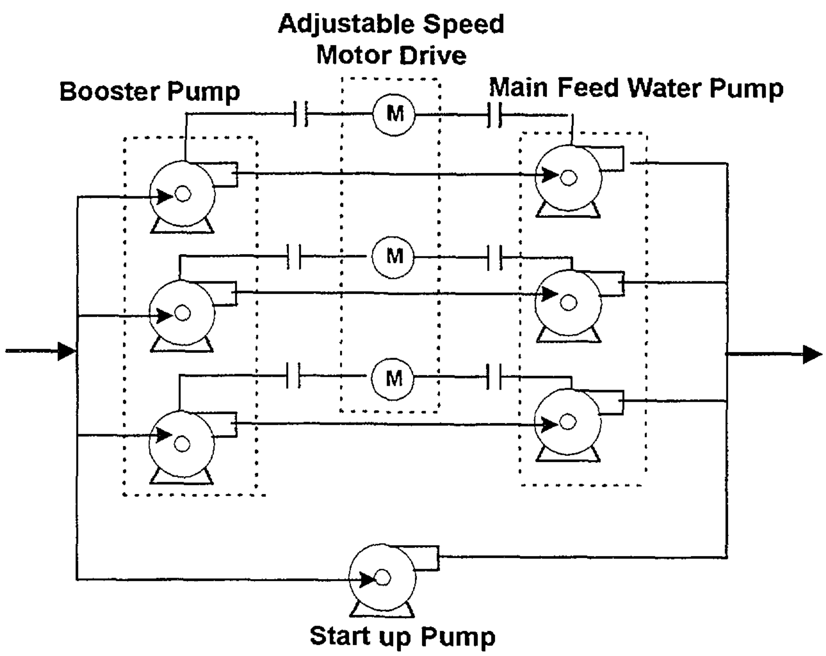

Fig. 3. New Arrangement of Main Feedwater Pumps.

2.2 Forced outage assessment

On the basis of the initial design configuration, forced outage is probabilistically assessed to identify significant systems and components. Although the assessment is not finalized at this time, it will be utilized to redesign systems, provide maintenance guidelines and implement the reliability centered maintenance (RCM).

FIG. 4 shows the work flow diagram for the analysis of unavailability caused by forced outages. The first step in the unavailability analysis is to collect plant operating experience

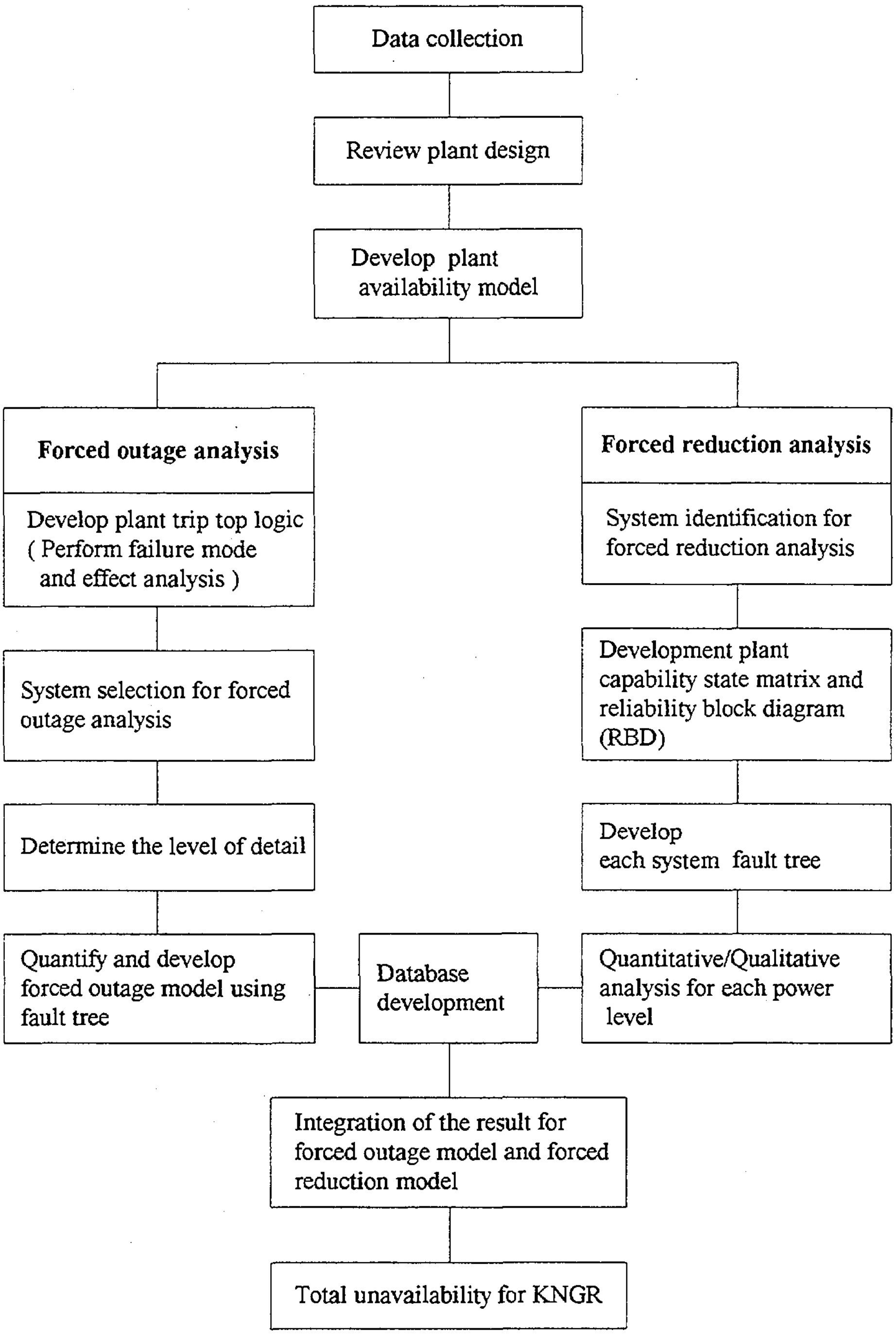

FIG. 4. Work Flow Diagram from Analysis of Unavailability Caused by Forced Outage for KNGR.

data. Since KNGR is not yet operating, however, the data are assessed based on Korean PWRs historical data and U.S. plant historical data. These data are used for producing the insights needed to predict its performance by which the level of modeling is determined.

The second step is to review the plant functional description and design documents for KNGR. At this step, the information needed, such as plant configuration, system function and operation, and the interface with other systems are reviewed. After this familiarization process, the plant availability model is developed. The plant availability model consists of two separate models, i.e., a forced outage model and a forced power reduction model.

To calculate total unavailability, these models are quantified by using the NUPRA computer code. The component failure data are used for the quantification of the plant availability model. The results quantified are represented as minimal cutsets along with their probabilities. And then the qualitative analysis is performed in order to check up to see if the results of the model are reasonable. The minimal cutsets from the availability model correspond to the component failure combinations which lead to a plant trip or a power reduction. These are ranked on the basis of their overall contribution to plant unavailability. Importance ranking of each systems and components which affects power production capability is measured in terms of Fussell-Vesely importance, Risk Reduction Worth and Risk Achievement Worth. The components of high importance thus identified need to be considered in detail.

The availability of KNGR is qualitatively checked with reference to Ulchin Unit 3 and 4, typical of Korean Standard Nuclear Power Plants (KSNP). Differences in design configurations are identified and the effects on plant availability are reviewed item by item. If a system is found to adversely affect plant availability, the system is redesigned depending on the results of the cost benefit analysis.

Some suggestions obtained from the evaluation results via each system analysis might lead to an availability improvement. These suggestions are then acceptable if they are easy to implement. After the effect on the overall KNGR availability is assessed, the suggestions are implemented and fed back into the analysis described in the previous section. This process is repeated until the target of the plant availability is met.

3. PLANNED OUTAGE

Planned outages, during which refueling and maintenance (R/M) is performed, is the most dominant factor to plant unavailability. Average planned outage duration for current nuclear power plants amounts to 47 days/unit · year, corresponding to 53 days per a planned outage during recent three-year period. Several action items have been identified to reduce planned outage duration for current domestic nuclear power plants, after the critical paths of the refueling and preventive maintenance work schedules had been analyzed in detail. Those action items shown below will be adopted in the KNGR design. As a result, outage duration is expected to be shortened about 5 days.

- Modulizing reactor head facilities
- Auxiliary crane for turbine maintenance
- Multi stud tensioner

3.1 Integrated head package (IHP)

It has been found that, prior to refueling in existing PWRs, the equipment on reactor vessel area has to be removed and temporarily stored before removing the reactor vessel head. This process has led to an increase the overall refueling time as well as the personal radiation exposure. An IHP is being designed to consolidate the following into an one-package component design: the head lifting rig; lift columns; missile shield; CEDM forced air cooling system; electrical and instrumentation cabling; insulation and reactor vessel head. The IHP lifts the reactor vessel closure head and the head area equipment at one time. Therefore, the amount of critical path time required to reach the reactor vessel internals can be reduced.

3.2 Additional design features

Furthermore, the KNGR will have advanced design features such as a permanent pool seal and a quick opening fuel transfer tube blind flange to reduce refueling work. A permanent pool seal is installed between the reactor pressure vessel and the surrounding refueling canal floor to permit flooding above the vessel during refueling. Since the leak-before-break concept is applied to the reactor coolant piping, the possibility of the local pressurization in the reactor cavity is eliminated. It becomes possible to permanently install the refueling pool cavity seal (termed as pool seal). Thus the need for assembling and disassembling temporary pool seals is eliminated.

The quick opening fuel transfer tube blind flange seals off the containment building transfer tube penetration sleeve during reactor operation. The current blind flanges are installed with bolts to be a part of the containment pressure boundary. Therefore, it takes long time to lift, and to temporarily store. The quick opening fuel transfer tube blind flange, however, can eliminate the need for lifting it from the area during refueling.

It is expected that these design features shorten refueling work as many as 2 ~ 3 days. So for the KNGR, it would take less than 45 days for refueling/maintenance (R/M) cycle per 18 months (i.e., 30 days/year). While current domestic nuclear power plants are operated with 12 ~ 18 month R/M cycle, KNGR is being designed to have a capability of operating on a 18 ~ 24 month fuel cycle, from post refueling startup to the subsequent post refueling startup as per EPRI URD [3].

4. EXTENDED OUTAGE

An extended outage is another type outage. Typical examples are;

- repair or replacement of large components
- manual trip resulted from unintended situation like steam generator tube leak

The current extended outage duration records as 2.3 day/unit · year during recent six years. Most of work performed during above extended outages is to repair major equipment such as generator, turbine, main transformer, reactor coolant pumps and so on. Kori Unit 1 has the 100 day schedule to replace steam generators (S/Gs) in 1998 including refueling and maintenance work. It is also assumed for KNGR that the S/G replacement can be performed in parallel with the refueling and maintenance outage. Assuming a 45-day R/M outage, the extension to the outage would be less than 55 days. Over the sixty-year period of the plant lifetime, this results in an estimated contribution to plant unavailability of less than 1 day per year associated with steam generator replacement.

There are some design features to reduce outage time by reducing corrosion, which are;

- lower hot leg temperature
- Alloy 690 for SG tube material

Although the quantitative estimation of their effects are difficult, the extended outage target of KNGR is assigned conservatively as 5 days.

5. FUTURE AVAILABILITY APPROACH

5.1 Availability improvement during the detail design stage

Since the plant configuration is almost set up at this stage, component level availability improvement is required as follows;

- enhancement of maintainability to be ensured for important plant components and sub-systems during the plant construction and operation;

  - built-in testability
  - on-line diagnostic and fault detection systems
  - repairability
  - replaceability

- development of procurement requirements for critical components (purchase for reliability and maintainability levels which are commensurate with their importance to reliability)

- use of maintenance simulation of R/M outages to identify critical path components whose periodic maintenance schedule can be changed (procurement specs) to minimize impact, or, whose maintenance schedule can be shifted from refueling to "at power" or "on-line"

5.2 Availability assurance through the RAP

Reliability assurance originated with the regulatory concern SECY-89-013 dated January 1989 where "Reliability Assurance Program (RAP)" was defined as a program to ensure that the design reliability of safety SSC is maintained over the life of a plant. Based on this document, ALWR designers have been setting up their own assurance program to ensure that their own systems meet all required safety regulations and requirements. Since it was considered that plant availability goals were generally beyond the purview of the regulatory bodies in their states, the vendors have been developing their own procedures which focus on achieving an economically competitive position and satisfying customer needs.

The EPRI URD requires D-RAP to ensure that sufficient plant reliability is designed into the plant to achieve overall availability goals, as well as to assure design reliability of structures, systems, and components whose reliability has a significant effect on core damage frequency. However, it does not detail how a reliability assurance program can be implemented throughout each stage of plant development, design, construction and operation, nor does it provide an integrated approach to incorporation of reliability and maintainability engineering in all aspects of plant decision making.

The Reliability Assurance Program which will be employed throughout design and operation of the KNGR is currently under development. Availability assurance will be continued through this RAP until the end of the commercial operation.

6. CONCLUSION

The unavailability caused from forced outages, planned outages and extended outages is assessed at the conceptual design stage to identify availability significant systems and components. As design progresses forward into detail, the assessment is also revised to reflect it. The plant availability will be ensured through RAP during all the phases of design, procurement, construction, startup, and commercial operation.

Above all things, planned outage time has to be shortened in order to improve the plant availability. It has been found that only the reduced refueling time can not reduce overall planned outage. Because turbine and generator maintenance process is of the critical path together with refueling process. Therefore, most of work will be concentrated to turbine and generator maintenance during the detail design stage to accomplish the KNGR availability target.

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