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Margin Benefit Assessment of A Digital Monitoring System for Existing Analog Plants

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기존 아날로그 발전소를 위한 디지탈 감시계통의 여유도 잇점평가

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Abstract

Margin benefits are quantatively assessed when a Digital Monitoring System(DMS) is assumed to be installed to an operating Westinghouse analog type plant. Applied plant and cycle is YongGwang Unit 1 Cycle 6. The referenced digital monitoring system is the COLSS(Core Operating Limit Supervisory System) of ABB-CE. Considered fuel design limits are DNBR and LOCA Fq. 200 3−D Power distributions within the present CAOC(Constant Axial Offset Control) limits are calculated for the analysis. The most limiting DNB prevention event of CEA Withdrawal is analyzed with the ROPM(Required OverPower Margin) concept of ABB-CE. The results show that the DMS can bring around 7% more margins for both DNB and LOCA Fq standpoints of view. The DMS can also monitor the PCI(Pellet-Cladding Interaction) limits.

요 약

운전중인 Westinghouse형 원자력 발전소에 디지탈 감시계통을 설치하였을 시의 정량적인 여유도 잇점을 계산하였다. 적용된 발전소는 영광 원자력 1호기 6주기이며 참조한 디지탈 감시계통은 ABB-CE 사의 COLSS이다. 고려된 핵연료 설계제한 한계는 DNBR과 LOCA Fq이다. 평가를 위해 기존 CAOC 한계내에서 200가지의 3−D 출력 분포를 계산하였다. 영광 1호기 6주기의 DNB 관련 가장 제한적인 사고인 CEA 인출사고를 해석하였다. 평가결과 DMS를 설치하면 DNB와 LOCA Fq 관점에서 모두 7% 출력 증가 효과를 가져올 수 있을 것으로 나타났다. DMS를 설치하면 PCI 한계도 감시할 수 있다.

1. Introduction

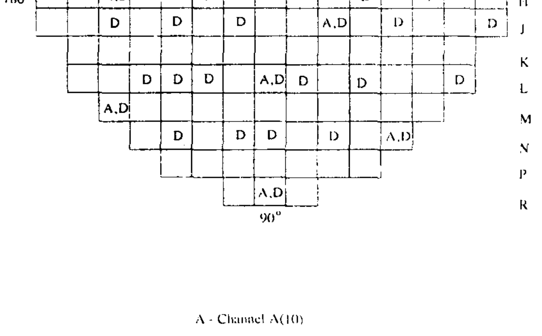
It is generally said that digital core monitoring and protection systems bring more margins to the plant, since they calculate the on-line core power distribution and DNBR. The margin benefits can be used to uprate the plant, to relax the core operating space, to reduce the fuel cycle cost and to extend the plant cycle length. Several Technical Specification surveillance requirements can be eliminated or relaxed. This includes the axial flux difference and quadrant power tilt. The core limit margin improvements can be utilized to provide operational flexibility and higher fuel utilization. The operational flexibility will allow more rapid return to power with lower borated water processing requirements. Fuel utilization improvements can be derived from higher peaking factor limit which permits lower leakage loading patterns. The on-line monitoring displays significantly improve the knowledge and understanding of the core. This permits informed, higher quality operational decisions which lead to improved operations. The improved knowledge also has significant benefits associated with a relaxation in the surveillance requirements related with an abnormal measurement such as quadrant power tilt or control rod misalignment.

EPRI URD [1] wants 15% margin, even if the exact definition of it is not clear. The amount of margin benefits of our studies are the differences between the calculated margins and the known amount of margin required for normal base load operations. We understand that YongGwang 1(YGN 1) Cycle 6 (Cy 6) has just enough margin at some point of burnup (most likely at BOC) for base load operation.

Since people are generally thinking of installing a digital core monitoring system on operating analog plants, it is needed to calculate the margin benefits of it. Installing digital core protection systems can be next step since it takes more efforts to upgrade the protection systems. Quantitative margin losses have been calculated when analog core protection and monitoring systems were installed to a digital plant (YongGwang 3&4) [2][3]. In this paper, a Digital Monitoring Systems (DMS) which is based on the COLSS (Core Operating Limit Supervisory System) of ABB-CE is used to assess the margin benefits when it is installed to the Westinghouse 3-Loop plant and cycle of YGN 1 Cy 6. Considered fuel design limits are DNBR and LOCA Fq. To assess the margins, the DMS is conceptually designed, the most limiting DNB prevention event of CEA Withdrawal is analyzed with the ROPM (Required OverPower Margin) concept of ABB-CE and all the needed analysis steps are quantitatively taken including 200 cases generation of 3-D power shapes within the present CAOC limits.

2. DMS Conceptual Design

YongGwang Unit 1(YGN 1) Cycle 6 (Cy 6) uses 50 movable incore detectors (Figure 1) (Channels A, B, C, D and E) to monthly calculate 3-dimensional core power distribution. It is assumed that 10 movable incore detectors of Channel A, which are shown in Figure 1, are modified to accommodate 5-axial-level Rhodium detectors of the YGN 3&4 Fixed Incore Detector System. The remaining 40 movable incore channels can still be used to monthly calculate



A - Channel A(10)
D-MOVABLE INCORE DETECTOR (50)

Fig. 1. Distribution of Incore Detecors of YGN 1

the 3−D power distribution without violating the Tech. Spec. incore detector operability limit of 75%. The on-line core power distribution and DNBR calculation algorithm of the COLSS is used for the DMS except using YGN 1 Cy 6 ERB−2 DNBR correlation instead of YGN 3&4 Cy 1 CE−1 correlation. Since the DMS calculates the on-line 3−D power distribution, it can monitor the PCI (Pellet-Cladding Interaction) pre-conditioning limits[6] (See Figure 2). The on-line measurement inputs of the DMS are 10 fixed incore channel signals, CEA positions, Pressurizer pressure, Cold Leg temperature (Tc), Hot Leg temperature (Th) and RCS flow rate (M_{RCS}). The major on-line products are 3-D peaking factor (Fq), planar radial peaking factor (Fxy), axial shape, DNBR, AO (Axial Offset), enthalpy rise factor $F^N_{\Delta H}$), core power, and alarm margins of DNBR, LOCA Fq and PCI limits. The three most important monitoring parameters of the DMS are DNBR, LOCA Fq Envelope (Figure 3) and PCI. The PCI monitoring is new added feature in the DMS.

3. Margin Assessment

Figure 4 shows the Overall Uncertainty Analysis (OUA) process of the DMS, which is the existing method of the COLSS. IQSBOX code, which is a KWU nuclear design code, generates 200 cases of BOC 3−D power shapes for YGN 1 Cy 6 within the CAOC (Constant Axial Offset Control, [4]) AO limits of solid lined of Figure 5. The BOC assessment is more limiting than other burnup points. Figure 5 shows the AO vs power diagram of the 200 cases (80 cases for 100% power, 40 for 80%, 40 for 50% and 40 for 25%). IQSEDT and IQSCOL codes of Figure 4 are file-editing codes. IQSGENI code samples the pressure, Tc and RCS flow rate within the LCO (Limiting Conditions for Operation) bound-

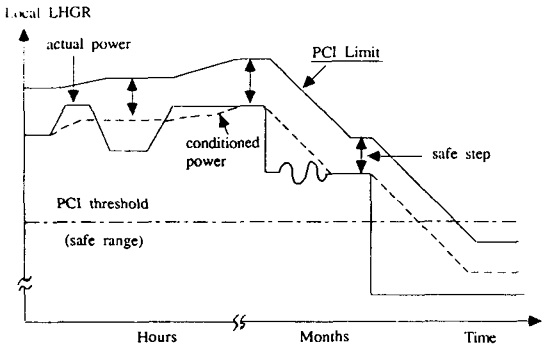


Fig. 2. Example of PCI Monitoring [6]

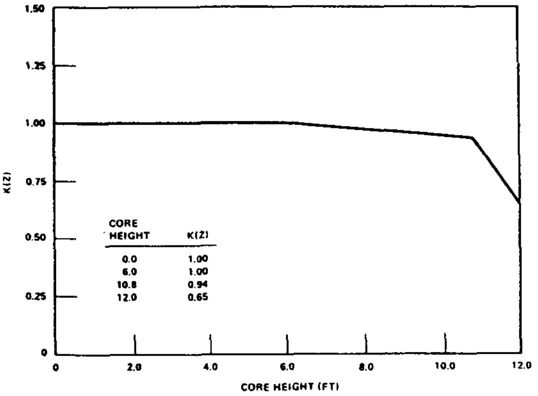


Fig. 3. LOCA F_q Envelope, which is normalized to 2.32 of YGN 1 Cy 6.

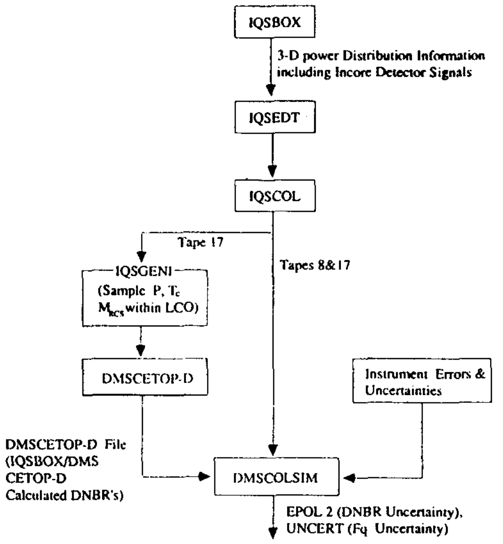


Fig. 4. DMS Overall Uncertainty Analysis Flow Chart with the SCU Method.

aries of 2220−2280 psia, 552.7−560.7 °F and 2.50−2.71 Mlbm/hr/ft^2. DMSCETOP-D is a modified version of ABB-CE's CETOP-D code. The modification is needed to switch the existing CE−1 DNBR correlation of YGN 3&4 Cy 1 to ERB−2 correlation of YGN 1 Cy 6.

The ERB−2 DSAL (Design Safety Analysis Limit) used in the DMS analysis is 1.60 of the present YGN 1 Cy 6, which is calculated with the ITDP (Improved Thermal Design Procedure, [5]). The ITDP method is conceptually very similar to SCU (Statistical Combination of Uncertainties) method of ABB-CE, which is schematically shown in Figure 4. The DMSCETOP-D code is conservatively tuned within the above P, Tc, and M_{RCS} LCO ranges to the PUMA of YGN 1 Cy 6 which is the KWU basic TH code. DMSCOLSIM is a modified version of the ABB-CE code of COLSIM, which is used to assess the OUA of the COLSS. The modification reason and direction are same as in the DMSCETOP-D. The OUA is to assess the DMS DNBR and Fq uncertainties by comparing the DMS calculated DNBR's and Fq's to those of IQSBOX and DMSCETOP-D as shown in Figure 4. The uncertainty factors considered in DSAL of ERB−2, DMS OUA, IQSBOX code and PUMA code are in Table 1. Table 2 shows the uncertainty factors used in LOCA Fq margin assessment including the LOCA analysis itself, where the LOCA Fq limit is 2.32 of the present YGN 1 Cy 6. Some factors of Table 1 and 2 are not explicitly considered since the design codes implicitly consider them. They are core inlet flow distribution uncertainties, which are covered by the PUMA code, reactor core simulation modeling error, which is covered by the IQSBOX code, and power distribution algorithm and thermal-hydraulic algorithm modeling uncertainties, which are covered by the OUA itself.

The ROPM for the DMS has to be calculated since it is better to use the ABB-CE Non-LOCA analysis method for the best use of the DMS if the DMS is installed in YGN 1 Cy 6. The ROPM is the power

Table 1. Uncertainty Factors in DMS DNBR Margin Assessment

1. ERB−2 correlation uncertainty
2. Engineering enthalpy rise factor
3. Engineering heat flux factor
4. TH code uncertainty
5. Tc measurement uncertainty
6. P measurement uncertainty
7. M_{RCS} measurement uncertainty
8. Power measurement uncertainty
9. Fxy measurement uncertainty
10. Core inlet flow distribution uncertainties
11. CEA position measurement uncertainty
12. In-core detector measurement uncertainty
13. Power distribution algorithm modeling uncertainties
14. Thermal-hydraulic algorithm modeling uncertainties
15. Computer processing uncertainties
16. Reactor core simulation modeling error

Table 2. Uncertainty Factors in DMS Fq Margin Assessment

1. Fxy measurement uncertainty
2. Engineering factor
3. Axial fuel densification uncertainty
4. Fuel assembly grid factor
5. Plant power measurement uncertainty
6. CEA position measurement uncertainty
7. Incore detector measurement uncertainty
8. Power distribution algorithm modeling uncertainty
9. Computer processing uncertainties
10. Reactor core simulation modeling error

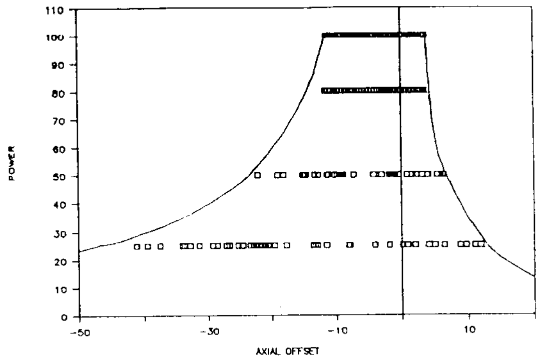


Fig. 5. Power vs AO for YGN 1 Cy 6 BOC 200 Cases with the CAOC Limits

margin set aside to accommodate the margin degradation during the limiting AOO (Anticipated Operational Occurrence) (See Figure 6). The most DNBR limiting AOO of YGN 1 CY 6 is CEA Withdrawal event. The ROPM is the equivalent amount of power change for the maximum DNBR decrease from the onset of the event to minimum DNBR time for all the initial condition combinations of the event within the LCO's. The calculated ROPM(See Figure 6) is 18% for the CEA Withdrawal event when it is calculated within the above LCO's. Figures 7 and 8 show the axial power shape comparisons between IQSBOX and DMS for YGN 1 Cy 6 BOC and EOC hot-full power equilibrium Xenon cases. These are quite similiar to the COLSS cases of Ulchin Nuclear 3 and 4 (UCN 3&4) Cycle 1 (Cy 1) Preliminary Design(PD), which are shown in Figures 9 and 10. The BOC and EOC power shapes of YGN 1 Cy 6 and UCN 3&4 Cy 1 are slightly different due to the different burnup points and different loading patterns. The marign benefits are calculated with the ROPM of 18%, DNBR and Fq uncertainties of the DMS OUA, Plant operating fluctuations or noises, and margin allowance of plant operation and maneuvering. The results show that there are 7.3% and 7.9% margin benefits of DNBR and LOCA Fq when the DMS is installed to YGN 1 Cy 6.

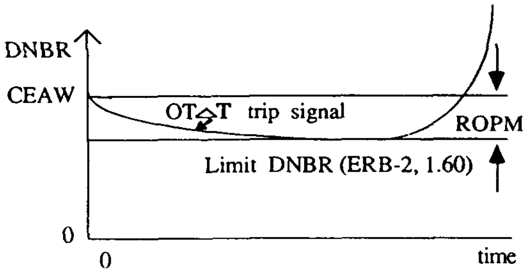


Fig. 6. ROPM and CEA Withdrawal Event for YGN 1 Cy 6 (Schematic Diagram)

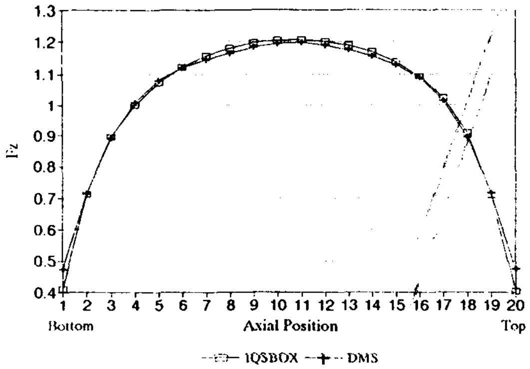


Fig. 7. IQSBOX vs DMS Axial Power Shape at YGN 1 Cy 6 BOC

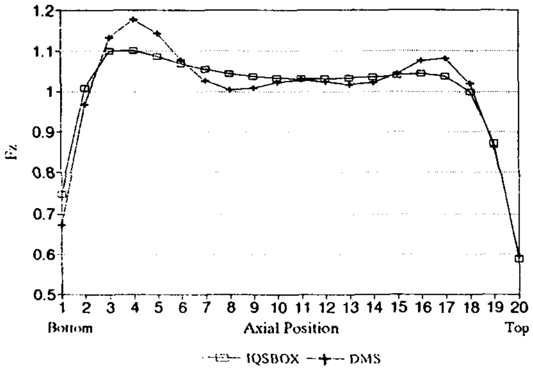


Fig. 8. IQSBOX vs DMS Axial Power Shape at YGN 1 Cy 6 EOC

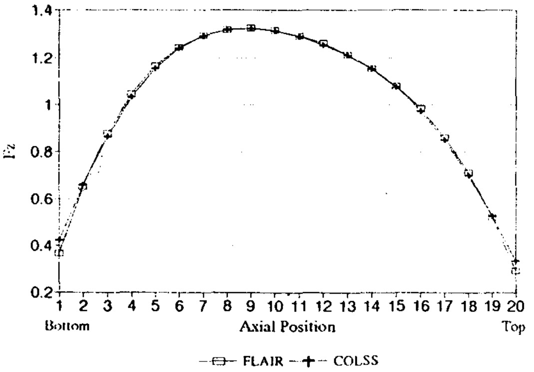


Fig. 9. Nuclear Design (FLAIR) vs COLSS Axial Power Shape at UCN 3&4 Cy 1 PD EOC

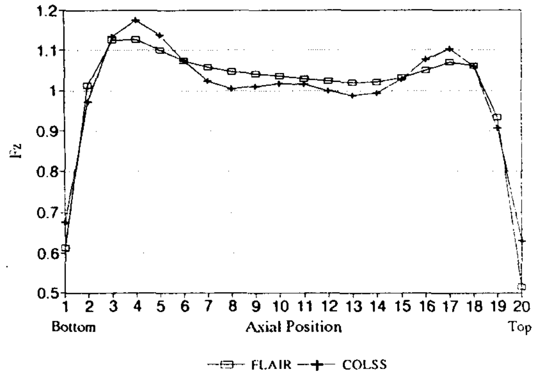


Fig. 10. Nuclear Design (FLAIR) vs COLSS Axial Power Shape at UCN 3 & 4 Cy 1 PD EOC

4. Conclusions

The quantitative margin benefits are assessed when the DMS is installed to an analog type plant of YGN 1 Cy 6. The referenced DMS is the COLSS of ABB-CE. The margin benefits are assessed within the existing LCO and CAOC limits with the ROPM concept accident analysis for the DMS. The resutls tell that the DMS can bring around 7% more margins for both DNB and LOCA Fq points of view. The DMS can also monitor the PCI limits and 3-D power distribution including quadrant power tilt, which will benefit the plant operation including plant startup tests and load-following operation. The margin benefits can be used to uprate the plant, to relax the core operating limits, to reduce the fuel cycle cost and to extent the plant cycle length.

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