Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 27-28, 2016

Analysis of the In-core Quadrant Power Tilt affected by Burned Fuel Shuffles of WEC Type NPPs in Republic of Korea

Seung-beom Son*, Jeong-pyo Jeon, Han-seung Song, Ki-bong Seong, Chae-joon Lim
KEPCO Nuclear Fuel, 242, Daedeok-daero 989beon-gil, Yuseong-gu, Daejeon 305-353, Republic of Korea
**Corresponding author: sbson@knfc.co.kr*

1. Introduction

Excessive core Quadrant Power Tilt (QPT) causes unreliability about designed power distribution and increases peaking factors in the affected core quadrants. The peaking factors are under surveillance during the cycle for the safe operation and the Quadrant Power Tilt Ratio (QPTR) is covered by the Technical Specifications [1].

Possible causes for QPT include manufacturing tolerance, asymmetric core configurations, operating conditions, and so forth, but the actual cause of specific core tilts frequently cannot be definitively identified. But nuclear designer continuously try to minimize the QPT by the general control of burned fuel distribution in a reload core.

For burned fuel, design rule for distributing symmetrical assemblies among the quadrants has been determined, which minimizes QPT due to burnup asymmetries that may be present among the burned assemblies, and that is called as "Burned Fuel Shuffles" strategy [2]. For fresh fuel, assemblies grouped by enrichment and number of burnable absorbers are randomly located in the manufacturing process for preventing the possibility of small reactivity variations.

This paper presents the designed Burned Fuel Shuffles (BFS) and the related results of measured In-core Quadrant Power Tilt (IQPT) in recent cycles of WEC (Westinghouse Electric Company) type NPPs (Nuclear Power Plants) in Republic of Korea. And the IQPT sensitivity results affected by BFS are also analyzed.

2. Definitions and Methods

The followings are definitions about QPT and BFSP, general actions based on IQPT and design techniques to minimize the IQPT. All the definitions and methods are came from the WEC "Core Tilt Design Policy" methodology.

2.1 Definitions of QPT & BFSP

Some definitions for core quadrant power tilt are listed as bellows.

1) Core Tilt : The ratio of maximum to average quadrant power.
2) In-core Quadrant Power Tilt (IQPT) : This condition exists when a core tilt is measured through the use of the Moveable Incore Detector System
3) Quadrant Power Tilt Ratio (QPTR) or excore tilt : A core tilt that is measured with the use of excore power range flux detectors.

Burned Fuel Shuffle Percentage (BFSP) is percentage of burned fuel assemblies shuffled into each shuffling angle category. A nodal code for core design calculates the shuffling angle of an assembly shuffles by determining the angle between the assembly's location in cycle N-1 and cycle N. Shuffle Categories by shuffling angle are listed below.

Cat.1 : shuffle angle is ≥ -45 degrees and < 45 degrees
Cat.2 : shuffle angle is ≥ 45 degrees and < 135 degrees
Cat.3 : shuffle angle is ≥ 135 degrees and < 225 degrees
Cat.4 : shuffle angle is ≥ 225 degrees and < 315 degrees

2.2 General Actions based on IQPT

IQPT is needed to monitor regularly to get surveillance data for design and safety evaluations as follows.

1) IQPT between 0% and 2% : No action
2) IQPT between 2% and 4% : Information only
3) IQPT between 4% and the RSE* separation line : Investigations into modeling and fuel rod design considerations
4) IQPT above RSE separation line : Re-evaluation of the RSE

* RSE : Reload Safety Evaluation

2.3 Design Techniques to minimize IQPT

Differences in burnup among quadrant symmetric assemblies may lead to large BOC reactivity differences. These reactivity differences can lead to unexpectedly high radial peaking factors and large measured to predicted power differences at BOC.

General nuclear design methodology suggests the guidelines that will reduce the effects of any differences in burnup between symmetric assemblies.

1) Cores Not Currently Experiencing QPT

- All Burned Fuels : even distribution into four BFS categories

2) Cores Currently Experiencing QPT

- Fuel with two or more cycles : Minimal category 3 shuffles and even distribution among category 1,2 and 4 shuffles
- Once burned Fuel : No category 3 shuffles and even distribution among the remaining categories (1, 2 and 4)

3. Results and Discussion

To begin with, Fig. 1 through 5 represent the BFSP state and the maximum IQPT in recent cycles of principal WEC type NPPs in Republic of Korea. Because real NPP cores are not ideal, IQPT forcing function can be always exist in some level.

Also based on the assumption that IQPT is mainly affected by BFSP of category 1 and 3, all the data were organized with focusing on those categories.

Results show the shuffles of burned fuel were applied properly according to the guideline suggested in design methodology and the results of actual measurement were all within the maximum 2% of IQPT guideline during the operation.

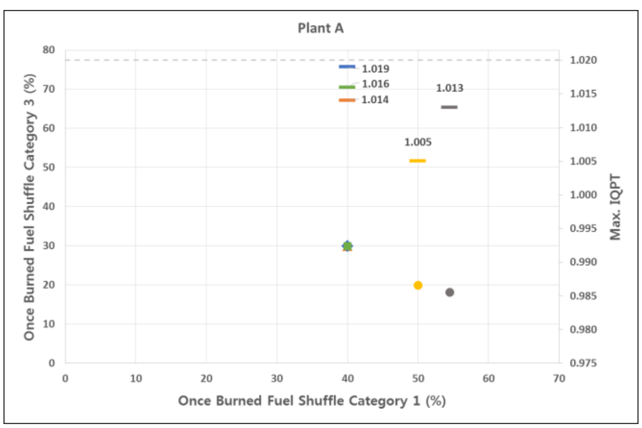

Fig. 1. Max. IQPT vs. Category 1&3 Percentage (Plant A)

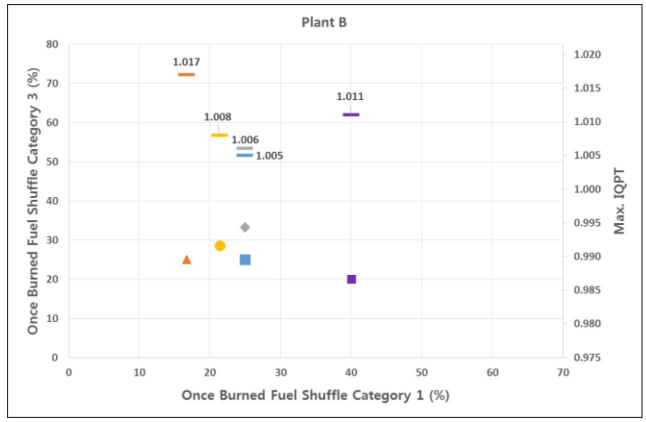

Fig. 2. Max. IQPT vs. Category 1&3 Percentage (Plant B)

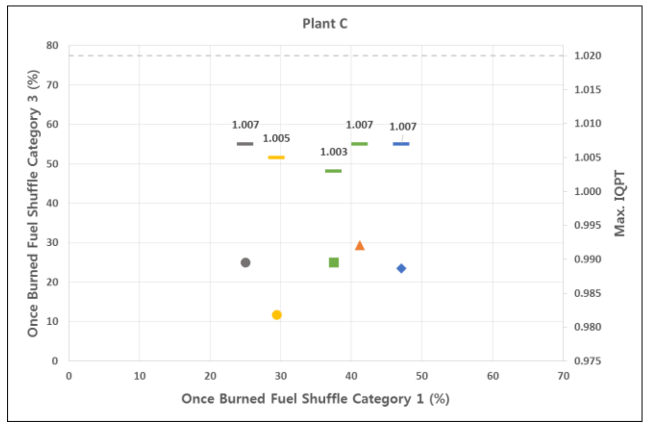

Fig. 3. Max. IQPT vs. Category 1&3 Percentage (Plant C)

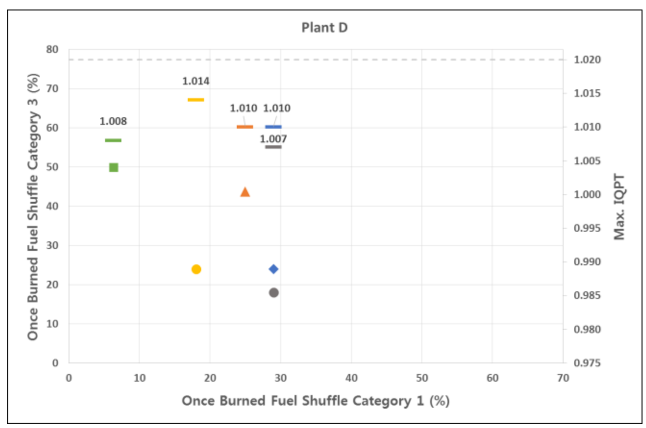

Fig. 4. Max. IQPT vs. Category 1&3 Percentage (Plant D)

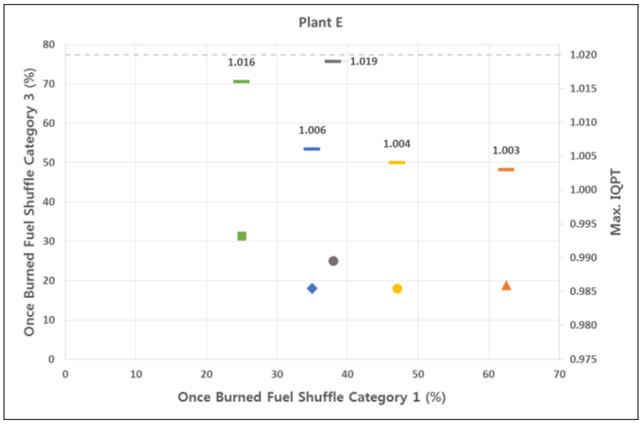

Fig. 5. Max. IQPT vs. Category 1&3 Percentage (Plant E)

As can be seen in the Fig. 6 and 7 below, the detail IQPT sensitivity was analyzed to consider the effect of category 1 and 3. The IQPT changes (%) between N-1 and N cycle were plotted by the changes of category 1 and 3, respectively.

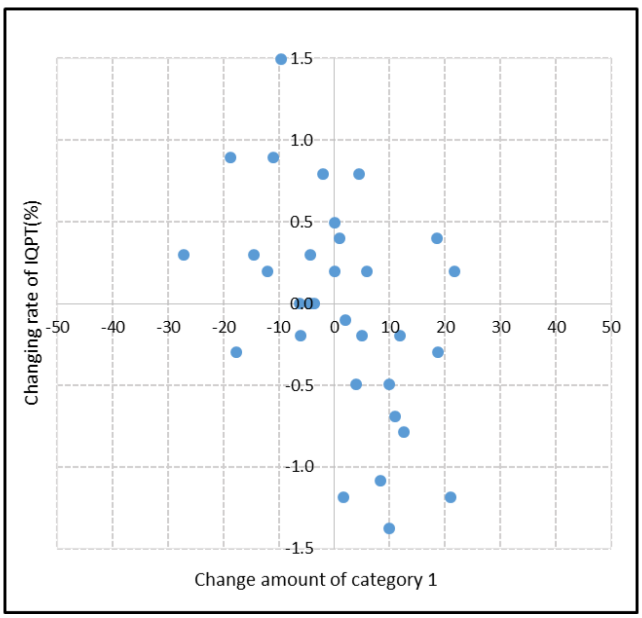

Fig. 6. IQPT Changes (%) vs. Category 1 Changes

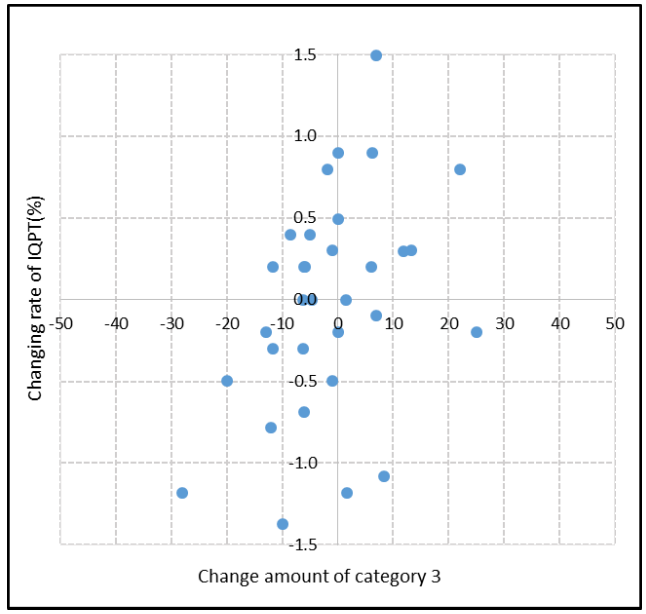

Fig. 7. IQPT Changes (%) vs. Category 3 Changes

Additional sensitivity analysis was also carried out to consider the combination effect of the category 1 and 3. Fig. 8 shows the changes (%) of IQPT at HFP BOC affected by the category 1 and 3 combination variable [(Delta BFSP of Category 3) - (Delta BFSP of Category 1)].

Even though there are some deviations, category 1 and 3 seems to impact on IQPT simultaneously and there can be seen the expected improvement tendency followed by the increase of category 1 and the decrease of category 3.

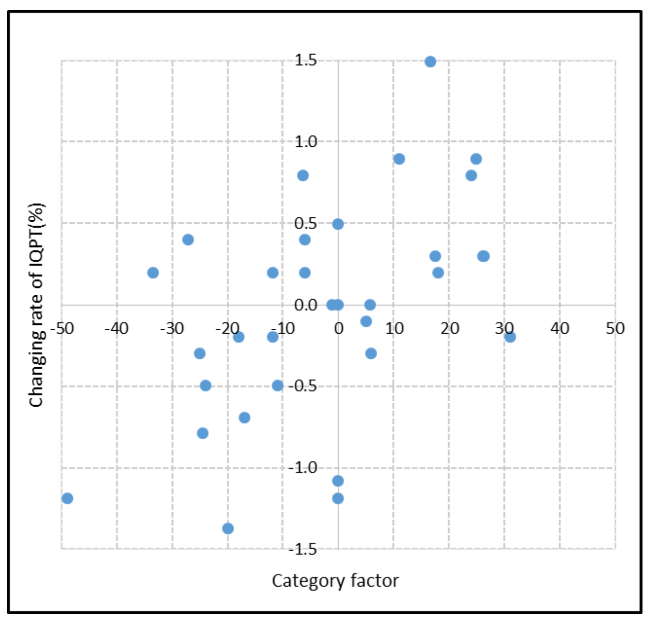

Fig. 8. IQPT Changes (%) vs. Cat. 1 & 3 Combination Variable

These results are consistent with the general design methodology in the category 1 and 3 tendency. The deviations in the plot seem to be affected just by the plant-cycle specific core characteristics.

On the other hand, the category 2 and 4 does not have reasonable IQPT tendency as shown in Fig. 9 and 10 below.

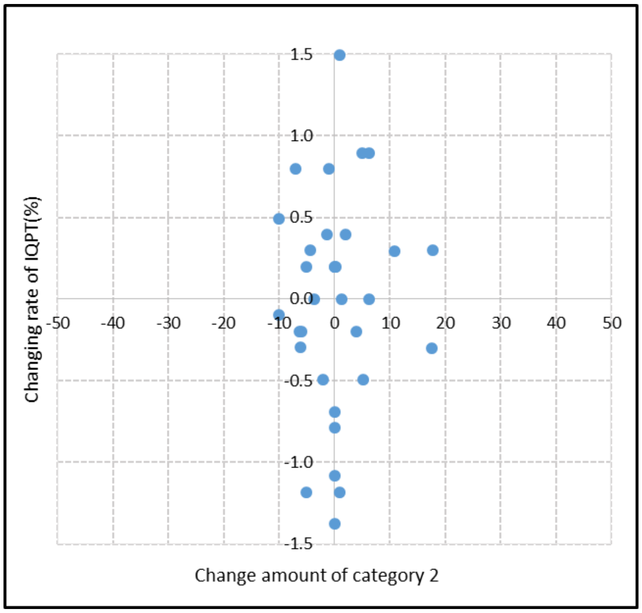

Fig. 9. IQPT Changes (%) vs. Category 2 Changes

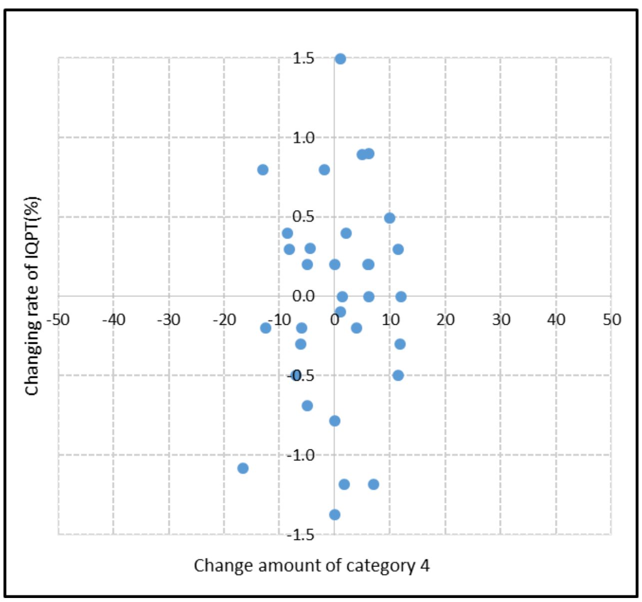

Fig. 10. IQPT Changes (%) vs. Category 4 Changes

4. Conclusions

In this study, the general guidelines of BFSP for effective mitigation of IQPT were introduced by references and the actual states of designed BFSP were analyzed for WEC type plant operating in the Republic of Korea. Results revealed that the BFSP was applied within appropriate level, which keeps IQPT below the level of guideline during the operations.

Also, the correlation between BFSP of category 1/3 and IQPT were quantitatively confirmed by the sensitivity analysis concerned with the change of BFSP. These results can be used as a reference to predict the expected IQPT with an appropriate BFSP on the WEC type reload nuclear design process.

5. Future Plan

Further to the analysis executed referred to the recent WEC type plant operated in the Republic of Korea, the determination of plant specific BFSP “IQPT Safety Zone” is expected through more data collection and analysis.

REFERENCES

[1] J. S. Kim, et. al., “The INCORE Quadrant Power Tilt Mitigation Experiences for Kori Nuclear Power Plant Unit 1”, PHYSOR, 2002.

[2] K. B. Seong, et. al., “Forcing Function Modeling for In-core Quadrant Power Tilt Simulation”, Proceedings of the Korean Nuclear Society Autumn Meeting, 2002.