Correcting the cusping problem in three-dimensional transients through NEM modification

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Due to LWR spatial heterogeneity in radial planes is more severe than axial heterogeneity, a few nodal methods homogenization procedures are restricted to radial planes. However the presence of control rods (CR) has increased axial heterogeneity and depending on how this heterogeneity is treated, the cusping problem, associated to CR, may arise.

The axial heterogeneities caused by the presence of CR generate difficulty for the nodal methods, when the rod is partially inserted in the node. A partially rodded node always occurs as soon as the location of the rod tip does not exactly matches the interfaces of the axial nodal discretization. The positions of the CRs are varied to compensate the changes that happen in the core of the reactor and they also to perform the occurrences of the power level and for the reactor shutdown.

In the implementation of a nodal model, the cross-sections are homogenized over an entire node. The existence of partially inserted CRs in the node causes an axial heterogeneity and generates a homogenization problem. If the homogenized cross-sections for this node are found through a volume-weighted procedure, the resultant nodal power distribution and the reactor multiplication factor may be inaccurate. This problem is accentuated by transients that involve CR motion. This way of representing a node partially filled with CR conducts to the phenomenon known as "CR cusping problem", and its name is because the curve of power level against CR position exhibits an unphysical cusp.

The present work describes an alternative method [1] to treat nodes with partially inserted control rods, grounded on the nodal expansion method (NEM), which was implemented in to a spatial kinetic code, to overcome the cusping problem.

The NEM is a spatial discretization method using the interface the interfaces currents and is based on the continuity equation and Fick's law.

NEM Modification for a Partially Rodded Node is given by

$$\hat{\Sigma}_{Xg}^{n} = f_{00}^{n}\,\Sigma_{xg}^{n,1} + (1-f_{00}^{n})\,\Sigma_{Xg}^{n,2} + (\Sigma_{Xg}^{n,1} - \Sigma_{Xg}^{n,2})\sum_{m=1}^{2} c_{mgz}^{n}\, f_{0m}^{n} \Big/ \phi_{g}^{n}$$

$$f_{0m}^{n} \equiv \frac{1}{a_z^n}\int_0^{z_c^n} P_m(z/a_z^n)\,dz = \begin{cases} (f_{00}^n)^2 - f_{00}^n & \text{for} \quad m=1 \\ -2(f_{00}^n)^3 + 3(f_{00}^n)^2 - f_{00}^n & \text{for} \quad m=2 \end{cases}$$

with $f_{00}^n \equiv z_c^n / a_z^n$.

The homogenization showed by above modifies one-dimensional diffusion equations for functions $\psi_{gu}^{n}(u)$, employed in the calculation of secondary coefficients of the expansion defined in the NEM.

In order to the three-dimensional core, adopted as benchmark, problem which introduced by Langenbuch, representing a simplified three-dimensional PWR model with 77 fuel assemblies had been analyzed.

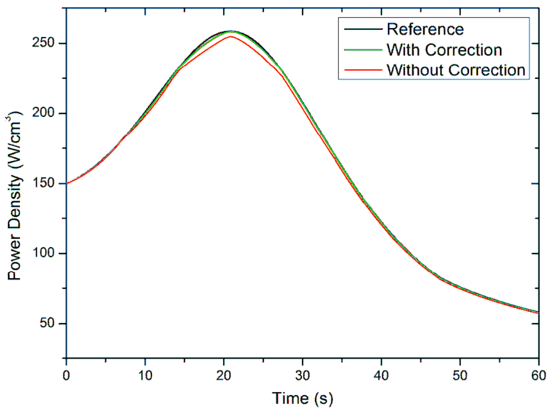

Figure 1. Variation of Power Density.

The method introduced satisfactory results in the case studied, where the cusping problem was corrected. In test, the cusping problem caused a small error, less than 3% in power density.

References

[1] Z. R. de Lima, A. S. Martinez, F. C. da Silva, A. C. M. Alvim, "Correcting the Cusping Prob in 3D Transients through NEM Modification". Nuclear Science and Engineering, v. 170, p. 66-74, 2012.