A Case Study of PHWR ROP Thermal Hydraulic Calculation Methodology

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1. Introduction

The Regional Overpower Protection(ROP) system is designed to prevent dryout in any fuel channel during a slow loss-of-regulation event. It accomplishes this through detectors in the core, which are designed to actuate reactor shutdown systems if a sufficient number of neutronic-flux detector readings exceed pre-defined ROP Trip setpoints (ROPT). These ROPTs are defined such that ROP will trip the reactor before any fuel channel exceeds its Critical Channel Power(CCP). Aging processes or operational preferences may cause changes to the primary Heat Transport System(HTS). These changes affect both flow and heat-transfer properties of the HTS as a whole. Due to HTS aging processes, the ROPT is required to perform a revaluation and reset.

Currently, KHNP is performing an ROPT Analysis Project for WOLSONG Unit2 with NSS. The ROPT Analysis process is done first to produce normal and abnormal flux shapes using a reactor core neutronics code; then, CCPs are produced by a Thermal Hydraulic(T/H) code reflecting aging parameters. It is necessary to evaluate each part (physics, T/H, uncertainty, Trip setpoint analysis) of new ROPT Analysis Methodology.

This paper provides a comparative analysis of the differences between AECL T/H calculation methodology used WOLSONG Unit1 ROP revaluation and NSS T/H calculation methodology for WOLSONG Unit2

2. CCP Calculation with AECL Methodology

One of the biggest differences between AECL and NSS T/H calculation methodology is the utilized code and the applied boundaries of these codes. Table1 shows the code differences and modeling boundary.

Methology	CODE	Modeling Boundary
AECL	NUCIRC	Below, Upper Header
NSS	NUCIRC	Below Header
	CATHENA	Upper Header

Table 1. Utilized Code and Modeling Boundary

NUCIRC is a steady-state one-dimensional thermal hydraulic code used for design and performance analyses of the CANDU Reactor Heat Transport System(HTS) and its components for a variety of operating conditions. NUCIRC is capable of modeling a complete figure-of-eight, two-quadrant model of the HTS but not all four quadrants. There are nine different simulation modules (ITYPE 1 to 9) in NUCIRC.

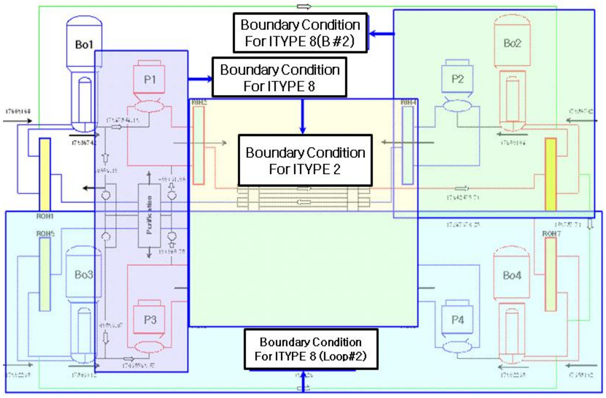

Figure 1. The Boundary of NUCIRC Modules

AECL T/H calculation methodology produces CCP with only NUCIRC. The first step in a full CCP analysis is the gathering of measured data associated with inlet header temperature (at 80%, 100% FP), header-to-header pressure(at 80%, 100% FP), and outlet header pressure(at 80%, 100% FP). The second step is modeling the divided HTS boundary with NUCIRC modules (ITYPE) based on measured data at 80% FP.

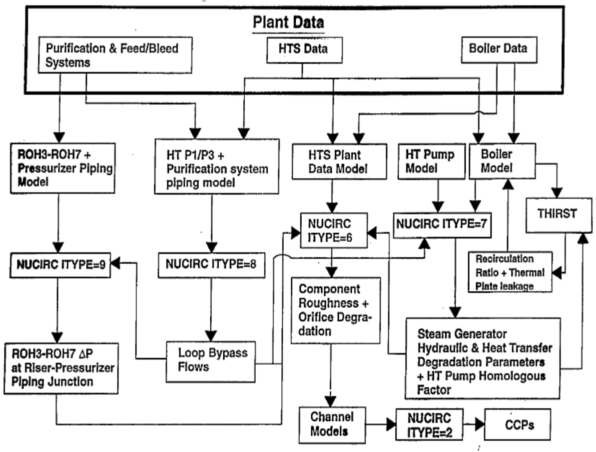

Figure 2. NUCIRC Modeling Flow Chart

In order to model approximate plant T/H conditions, various factors are defined and tuned. The tuning factors are shown below. The third step is to produce CCP at ITYPE2 with 100% FP measured data using the tuning factor made in the second step.

Boundary	Tuning Factor	ITYPE
Below Header	Orifice Degradation	ITYPE2
	Pressure Tube Roughness	ITYPE2
	Feeder Roughness	ITYPE2
Upper Header	Pump Homologous	ITYPE6
	Boiler Roughness	ITYPE7
	Boiler fouling	ITYPE7

Table 2. NUCIRC Tuning Factor

3. CCP Calculation with NSS Methodology

Contrary to the case of AECL T/H calculation methodology, NSS methodology uses both NUCIRC and CATHENA. CATHENA is a one-dimensional, two-fluid thermal hydraulic code designed for analysis of two-phase flow and heat transfer in piping networks. Usually this code is used for Safety Analysis. The primary focus of the development has been to allow the analysis of the sequence of events that occurs during a postulated loss-of-coolant accident in a CANDU reactor. But the main function of CATHENA, utilized in NSS methodology, is to predict Boundary Conditions such as inlet header temperature, header-to-header pressure, outlet header pressure at any Reactor power, even when Boundary Conditions(B.C.) are not measured.

The first step for CCP analysis is the gathering of measured B.C.(80%, 100% FP). In addition to B.C. data, NSS methodology requires measurement of flow data for twelve channels flow. The second step is modeling the Below Header boundary. While AECL methodology uses Calculated Heat Balance Flow as Reference Flow, NSS methodology uses measured flow as Reference Flow for tuning. It accomplishes this by tuning the Orifice degradation, Pressure Tube roughness, and Feeder roughness in NUCIRC ITYPE2 with measured B.C. and twelve Channel Flow at 100% FP. Then, the100% FP Below Header model is verified, adjusting tuning factors for 380 Channels conservatively with B.C data at 80% FP. The third step is making the full HTS circuit model with CATHENA. In order to model approximate HTS conditions, the tuning of the CATHENA aging model requires adjusting various factors like boiler tube roughness, boiler tube fouling, inlet/outlet Feeder roughness, and inlet/outlet form loss coefficients. For NSS methodology, CATHENA is used to predict Boundary Conditions at various levels of Reactor Power.

NSS methodology applies a new concept to reduce uncertainty defined as Power At Trip (PAT). CCP will be independent of reactor power if HTS conditions do not change. However, in a postulated LOR event with bulk power increase, all fuel channels experience a power increase. This could affect the overall T/H conditions in the headers, potentially degrading the CCP values. To account for this, CCP values are corrected to reflect the overall T/H conditions corresponding to the reactor power at which an ROP trip would occur. These PAT corrections to the CCP are computed independently for every fuel channel, for each Shut Down System(SDS) for every flux shape. The corrections depend on the power at which a trip will occur for a given perturbation and therefore on the detector signals. The detector signals of distorted flux shapes are different for SDS1 and SDS2, and therefore each flux shape has a different SDS1 and SDS2 PAT correction.

The fourth step is below.

1) Calculating CCP for every channel for steady-state, nominal conditions for various Power levels (using B.C. predicted by CATHENA)for example, 85%, 90%, 98%, 100%, 103%, 105%,110%.
2) Calculating ROPT with CCP at 100% FP
3) Calculating powers at which trip occurs for each SDS of each flux shape
4) Calculating the PAT corrections to CCP for each channel of each flux shape.
5) Re-calculating the ROPT using the corrected CCP(for each SDS).ROPT analysis code uses linear interpolation if the PAT is between two of the analyzed power levels and ignores beneficial corrections.
6) Iterating this procedure if required

4. Conclusions

The final purpose of T/H Calculation is to produce CCP to be used in Trip Setpoint Analysis. To prevent any fuel channel from dryout during a slow loss-of − regulation event, accurate tracking of HTS conditions is significant on T/H model development

AECL T/H calculation methodology and that of NSS have many differences such as utilized Codes, modeling boundary and the PAT. Application of PAT makes major difference of two methodologies. It seems that PAT decreases the uncertainty due to reflection of the T/H boundary condition at the Reactor Trip. T/H calculation is included dependently in the ROPT analysis Methodology. Further evaluation of both T/H methodologies using the same HTS conditions is required to obtain a more specific comparative analysis.

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REFERENCES

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