Ringhals-1 BWR Stability Analysis With TRACE/PARCS

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ABSTRACT

This work is framed in nuclear safety field in BWR. This kind of nuclear power plants has suffered several instability cases, whose dominant mode is the one that combines neutronic and thermal hydraulic effects. In order to realize different studies about them, the analyst requires computer codes that have to be able to represent with high reliability the physical phenomena that take place during an instability event. In addition, computer codes are necessary to the reactor licensing, following the SRP guide from the NRC. Previously, these computer codes have to be validated.

The aim of the present work is to collaborate in the validation of the methodology TRACE v5.0/ PARCS v3.0 for instability simulations. In particular, we reproduced the data available in the NEA Ringhals I BWR Stability Benchmark and compared to those obtained for the reactor core and the results with a model of the complete vessel.

The operational point selected is Record 9 from cycle 14. The reactor core was modelled with 72 thermal-hydraulic channels, 71 represent the active core and one representing the core bypass. In order to design this configuration, the azimuthal modes have been taken into account. With this mapping, the possibility of conditioning the oscillation configuration is avoided.

The vessel model includes also pumps, downcomer, separator and dryers. The perturbation carried out consists of a control rods movement, which causes a larger excitation to the subcritical modes, leading to the expected out-of-phase oscillation. Therefore, the results allow the validation of the procedure using TRACE v5.0/PARCS v3.0 for stability analysis.

1 INTRODUCTION

Boiling water reactor (BWR) stability has been an issue of great concern since the beginning of BWR life, caused by the different instability events occurred at these reactors. Due to this concern, different researches have been carried out, and now it is known from a theoretical (and empirical) point of view that a BWR with negative reactivity coefficients might reach operational points with power oscillations [1]. Nowadays, these operating points can be avoided and left outside the limits of the power-flow map of the reactor using a monitoring system. However, the physical phenomena which is behind an instability is not fully understood yet. So due to this reason, and the fact that the codes that are used for BWR
transient simulations are still not capable of predicting, with a total reliability, the reactor behaviour against some perturbations [2], leads to the need of continuing to develop and validate methodologies for BWR transient simulations.

In this work, three dimensional time domain BWR stability analysis has been performed in Ringhals 1 NPP, using the coupled code TRACE v5.0 patch3/PARCS v3.0.

The system code TRACE/PARCS is used by the U. S. Nuclear Regulatory Commission to carry out stability analysis in BWR reactors. But this methodology is still in validation period, as previous works [3, 4] demonstrate.

Therefore, the aim of the present work is to collaborate in the validation of the methodology TRACE v5.0/PARCS v3.0 for instability simulations. In this context, we have selected the NEA Ringhals I BWR Stability Benchmark.

In order to validate the procedure, the results obtained have been compared to previous results that correspond to the same model, but by means of RELAP5/PARCS methodology. This work, which was previously validated, was carried out at Universitat Politècnica de València (UPV) [5] and it is the reference for this work.

This work is structured as follows: Section 2 explains the methodology, section 3 shows the description of the model, the results are analyzed in section 4 and the main conclusions of this work are presented in section 5.

2 METHODOLOGY

As already mentioned, this work was carried out using the coupled system code TRACE/PARCS. In order to achieve the results, it is necessary to complete the following procedure:

1. PARCS stand alone steady state run.
2. TRACE stand alone steady state run.
3. Coupled TRACE/PARCS steady state run.

The cross sections set was previously obtained by the SIMTAB methodology [6] and they are defined by means of the fuel temperature and moderator density. The set consist of 1303 different compositions considering 53 different fuel elements, which are written in two files called nemtab (for unrodded compositions) and nemtabr (for rodded compositions).

In case of TRACE stand alone steady state step, the first stage is to model the core. The description of the model will be developed in next section, but for a better comprehension of the methodology, we can bring forward that the core has been modelled with 72 thermal hydraulic channels, including the bypass. In order to do this distribution, it has been taken into account the next coupling with PARCS.

The best coupling structure for thermal hydraulic and neutronic nodes would be those where the number of fuel elements in the reactor core were the same in both types. Since the simulation of a whole core in TRACE implies large computational efforts, the fuel elements are usually grouped in a lower number of components. This division has been done through the lambda modes, with the aim of not disturb the oscillation pattern. The Lambda modes are acquired with VALKIN, which is a 3D neutronic code developed at UPV that calculates the time evolution of the neutron flux and its harmonics (modes) during a transient.
In order to do the mapping, the three first harmonics are taken into account. First, the mapping is divided in four quadrants according to the first and second mode. Then, the fuel elements are grouped according to the value of the fundamental mode (which is divided in intervals) and the fuel design characteristics [7]. Figure 1 shows the final mapping.

![Thermalhydraulic channels](image)

**Figure 1: Thermalhydraulic channels.**

### 3 MODEL DESCRIPTION

In order to perform this work, we have selected the NEA Ringhals I BWR Stability Benchmark, in particular, record 9 of cycle 14. At this operating point, out-of-phase oscillations were recorded.

Ringhals 1 is an ABB design BWR whose nominal thermal power reaches 2270 MW and its total core rated mass flow comes to 11550 kg/s. Table 1 presents a summary of the core working conditions.

<table>
<thead>
<tr>
<th>Point</th>
<th>Power (%)</th>
<th>Flow (%)</th>
<th>Frequency (Hz)</th>
<th>Decay Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rec. 9</td>
<td>72.6</td>
<td>52.4</td>
<td>0.56</td>
<td>0.8</td>
</tr>
</tbody>
</table>

The reactor core has been modelled in 72 thermal hydraulic channels, 71 correspond to fuel elements and 1 corresponds to the bypass (see section 2).

Radially, the neutronic model has been modelled in a one-to-one basis model, so each fuel element is represented by a radial node and the core is surrounded by reflector nodes. Thus, a model with 648 radial nodes is accomplished. Axially, 27 axial planes have been defined, where both the top and the bottom planes are reflectors.
The procedure has been applied to a model in which only the core has been included. Thus, the 71 thermal hydraulic channels are represented by the TRACE component CHAN, which are connected to a FILL component at the inlet and to a BREAK component at the outlet. The FILL and BREAK determine the boundary conditions. Working with the core model allows determining the core characteristics in a simpler way. Figure 2 shows a representation made with the SNAP tool of the final core model.

![Figure 2: SNAP representation of the core model.](image)

4 SIMULATION RESULTS

4.1 Steady State Results

As mentioned before, first step is to ensure PT9 conditions. The objective is to adjust the mass flow within the channels and bypass and also the pressure drop along the channels. The main parameters taken into account to adjust the model are the friction factors, and also the friction calculation method, due to the fact that TRACE has different methods to calculate the friction, but RELAP has only one.

Figure 3 shows the final mass flow radial distribution. Since the cells are too small to see the numbers, the distribution has been represented by colours. The red colour means a negative difference, and as the reference is RELAP case, this means that in red cells the mass flow in TRACE simulation is lower than in RELAP. The opposite takes place in green cells, where TRACE mass flow is larger. The mean relative error of the whole core is 4.5%. Two dark green cells are highlighted, because of their value. The error in these cells are 20%, almost twice as much as any other cell.
shows the total power of the simulation. Although Ringhals went into instability, whereas in the top side of the core, the TRACE case power is slightly higher than RELAP case. Nevertheless, the profiles match, and the RMS error is 0.99%.

4.2 Transient Simulation

Once the steady state has converged and it has been proved that operation conditions correspond to Record 9, the transient has been run. Although Ringhals went into instability due to the conditions themselves of Record 9, the transient has been simulated with a control rod movement in order to perturb the model as it was done in the reference case. The control rod movement takes place since the beginning of the transient during 5 seconds. Figure 5 shows the total power of the simulation.
Since the total time evolution is chaotic and it is difficult to see some details, figure 6 shows the power for first 25 seconds.

Although both transients start from the same point, it is difficult to compare both profiles due especially to the peaks obtained in TRACE. The numerical damping causes not only the largest peak, but also the next ones, so the relation between the nodalization and the time step is not well achieved.

The frequency also differs significantly. In RELAP, the mean frequency is about 0.56, very close to the benchmark. In contrast, frequency average in TRACE is 0.75, during the initial oscillation. In addition to that, from the main peak on, the simulation in TRACE turns into more chaotic, so next figures will be compared until $t = 9s$.

In order to analyse what kind of instability has been found, it is interesting to see the power in some channels. For this purpose, we have selected four channels, one for each quadrant, to compare the power in opposite channels. Figure 1 shows the selected channels.
Figure 7: Relative power for opposite channels 120 and 139 in both RELAP (left) and TRACE (right) simulations.

Figure 8: Relative power for opposite channels 109 and 163 in both RELAP (left) and TRACE (right) simulations.

The relative power profile shows that opposite channels oscillate out-of-phase, as it can be seen in figures 7 and 8. These figures also confirm that TRACE simulation starts from the same conditions as RELAP, although TRACE gain is larger than RELAP, and whereas the transient is in progress, the amplitude grows up. Nevertheless, the trend in both simulations are similar, as well as the oscillation.

5 CONCLUSIONS

The aim of this work was to validate the TRACEv5.0/PARCSv3.0 methodology for instability simulations. The case selected was Record 9 of Ringhals-1 NPP, where an out-of-phase oscillation was found.

The thermal hydraulic model consists of 71 thermal hydraulic channels plus 1 channel that represents the bypass. Boundary conditions corresponding to Record 9 define the case. The neutronic model includes a cross section set with 1303 composition, and the mapping is defined with the aim of not disturb the oscillation pattern.

The results in the steady state case show that the power profiles of the methodology presented and the reference match with high reliability. This means that the pressure drop distribution along the channels is well achieved, although the power peak of RELAP/PARCS is still slightly higher.
The transient has been run with a control rod movement at the beginning of the transient, although the conditions themselves of Record 9 lead to an instability. The power evolution on the channels allows us to confirm an out-of-phase oscillation.

Therefore, this work contributes to the methodology of TRACEv5.0/PARCSv3.0 to be validated in the simulation of out-of-phase instabilities, but there is still margin to improve. It is necessary to deal with the numerical damping.

Future work will deal with vessel and the rest of component, such as separator, recirculation pump and downcomer.

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REFERENCES


