7ICMSNSE-048

Simulation of a Turbine Trip Transient at Embalse NPP with Full-Circuit CATHENA Model

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Abstract

Embalse NPP is carrying on a Periodic Safety Review to deal with its life extension. This review includes tasks like Deterministic Analysis review for the Final Safety Analysis Report.

In 2011, NA-SA (Nucleoeléctrica Argentina S.A.) issued a first CATHENA full-circuit model representing the current plant. This model is used in this work.

The simulation presented here corresponds to a turbine trip that occurred at Embalse NPP. Consistency between the simulation and the real event is demonstrated.

Furthermore, NASA is currently performing Safety Analysis with a new model developed jointly with AECL and Candu Energy which includes post refurbishment changes and other improvements.

Keywords: Thermalhydraulics, Computer Codes and Modelling, CATHENA, CANDU.

1. Introduction

The code CATHENA (Canadian Algorithm for THErmalhydraulic Network Analysis) (Ref. [1]), developed by AECL (Atomic Energy of Canada Limited) and acquired by NA-SA, allows the user to represent the thermohydraulic behaviour of CANDU plants during a steady state and during a transient.

CATHENA is a one-dimensional code used to model thermohydraulic phenomena, particularly those that may occur in horizontal fuel channels such as in CANDU plants. From a generic nodalization of a CANDU 600 nuclear reactor, received by NA-SA from AECL, a large number of updates and adjustments were made in order to represent in greater depth and detail the different systems that comprise the CNE (Central Nuclear Embalse).

The purpose of this paper is to describe the behaviour predicted by the model against a transient occurred in the Secondary System of the CNE and compare simulation results with plant measurements. This work is part of a program of simulations of plant transients and the selected transient for this paper is a turbine trip due to a spurious high level signal in a tank of an auxiliary system which occurred at the CNE in 2007.

2. CNE model for CATHENA code

Plant systems included in the model are: Primary Heat Transport System (PHT), Core, Steam Generators (SGs), Secondary Heat Transport System (SHT), SG Level Control (BLC), SG Pressure Control (BPC), Pressure and Inventory Control System (PIC), Emergency Core Cooling System (ECC) and Reactor Power input table. The model also includes all related control systems with the different systems. In the next section, the SHT is described.

2.1 Secondary Heat Transport System (SHT)

Heat is transferred from the PHT to the SHT through SGs. The light feedwater is extracted from the condenser and then preheated before entering the SGs. There are three low pressure feedwater heaters. Three feedwater pumps (P102 pump), two in normal operation, drive the water towards a collector which then sends the water to the four SGs.

The steam generated in each SG flows through 4 separate pipes with Atmospheric Steam Discharge Valves (ASDVs) and Main Steam Safety Valves (MSSVs). The four steam lines from the SGs are connected to a main steam header. The steam leaves the header and enters the turbine through the Turbine Governor Valves (TGVs). In case of unavailability of the turbine, there is a steam bypass to the condenser, through the corresponding discharge valves, the Condenser Steam Discharge Valves (CSDVs).

The SHT model represents in detail each preheating train (Figure 1). The feedwater passes through four stages of preheating and enters the SG from the main collector represented by the BFW pipe. SGs are included in the Figure 1 as B1 to B4.

The model starts with the boundary condition CNE800, which represents a light water supply at a fixed temperature prior to entry into the preheating.

3. Results: Comparison between the CATHENA model and the plant

In order to determine if the model correctly represents the dynamics of the plant, it is necessary to compare the plant measurements with the results of CATHENA simulations during the steady state prior to the transient and during the transient itself.

To compare the model with the plant, it is necessary to obtain a considerable amount and quality of plant data. The plant (in the last decade of operation) has a digital system of permanent collection of accessible information. Furthermore, until a Shutdown System (SDS) is tripped, this information is saved every 5 seconds. After a reactor trip, the variables associated with the SDS are recorded and stored every 0.1 s.

In general, the first part of the transient (the first few seconds) should have an important detail, since the operator then begins to take action. Continuing the simulation of the transient would be necessary to simulate the operator actions. In particular, in this event, the operator increases the feedwater temperature in two opportunities, at 3750 and 3950 s.

Each of the simulations enables to model improvements and achieve a better representation of plant behavior in different situations. Furthermore, a great number of performed simulations mean better training of specialists and greater knowledge about plant behaviour and model accuracy to represent it.

In order to show the behavior of the plant model during a transient, a turbine trip, which occurred in CNE in 2007, was selected for simulation.

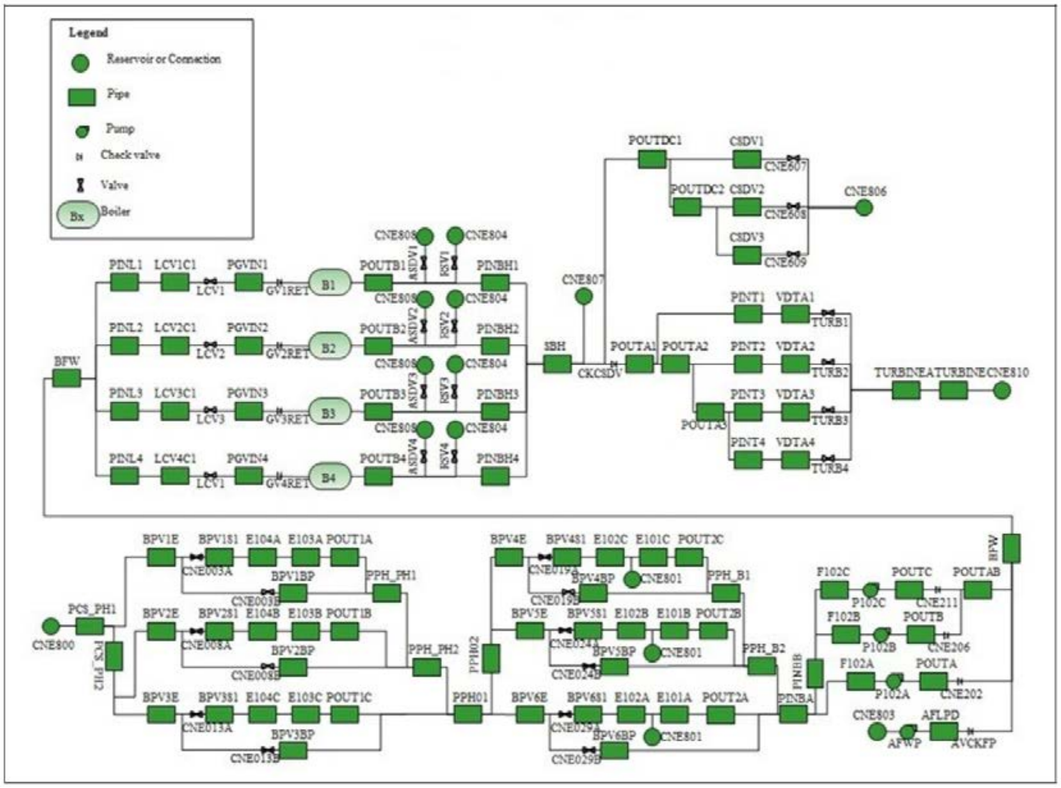

Figure 1. CATHENA model of Secondary Heat Transport System.

3.1 Description of the event

Plant data and simulation results are presented In Figures 2 to 8. Turbine trip is modelled to occur at 3200 s. In all cases pressure are gauge pressure.

The plant behaviour was as expected. With the TGV closing, the steam flow to the turbine is interrupted and the SHT pressure increases. The reactor regulating system acts quickly to rundown the power to 49% FP.

If there is sufficient unbalance between the turbine and the reactor power, the ASDVs and CSDVs valves must open to manage the steam and to control the pressure increase in the SGs. The plant measurements show that ASDVs open and close in a period of 3 seconds. In plant data output every 5 seconds this opening is not observed, but the CSDVs opening is registered (Figure 2).

In this event, at 960 s. after turbine trip, the reactor is tripped on the SDS1 Low SG Nº1 Level due to a malfunction of its feedwater valve. This event is out of simulation time.

The feedwater preheating lines have temperature measurements in the different stages. The SGs feedwater temperature drops because of the interruption of steam flow to turbine, and from there to the main steam extractions to the preheaters. However, around 3600s (400s after turbine trip), the operator opens the valves connecting the main steam extractions to the preheaters to maintain the feedwater temperature. In Figure 5, the plant data displayed this behaviour. In this work, this manual action is not modelled because modelling these actions would not provide any relevant result.

3.2 Preparation of steady state for transient simulation

The first step in transient simulation is to achieve a steady state consistent with the plant data. This transient occurred in 2007, so the user must work with roughness and steam generator fouling updated data to adjust the plant values. These roughness and steam generator fouling were calculated roughly as they are not easy to predict. The used values correspond to those expected based on experience in other similar plants. Therefore, prior to the simulation of the transient, a 3200 s. steady state simulation is performed.

In Table 1, a comparison between main parameter values of plant measurements and simulation results is done.

The TGV opening is somewhat higher in the steady state simulation that the one measured at the plant before the initial event, thus leading to review the losses in the steam pipes. However, this difference has no impact on the behaviour of the simulation during the transient as is deductible if the evolution of the secondary pressure calculated by the simulation is compared with the measured pressure at the plant (Figure 3).

Event simulation is performed based on a model that does not perfectly simulate the aging of the entire plant. For this reason, the inlet header water temperature in the simulation is somewhat higher than plant measurements at the beginning of the transient (Table 1). This also has an effect on the amount of steam present in the PHT and causes some differences in calculated pressurizer level before TGV closing.

3.3 Comparison between the simulation results and plant measurements during transient

At 3200 s, TGVs closing is modelled following the closing of these valves at the plant (Figure 2). Furthermore, reactor power reduction is entered as a boundary condition.

		Steady state between 3100 and 3200 s		
		Plant	**CATHENA**	**Error (%)**
POWER (FP)		1.0061	1.0062	0.010
Inlet Header Temperature (ºC)	**IHD2**	264.273	265.905	0.617
	IHD4	264.112	265.972	0.704
	IHD6	264.190	266.028	0.696
	IHD6	264.840	266.063	0.462
Outlet Header Pressure (g) (kg/cm^2)	**OHD1**	100.774	100.742	-0.032
	OHD3	100.693	100.691	-0.002
	OHD5	100.764	100.755	-0.009
	OHD7	100.561	100.654	0.092
PHT Pump Suction Pressure (g) (kg/cm^2)	**P1**	96.586	97.318	0.758
	P2	95.634	97.264	1.704
	P3	96.193	97.319	1.171
	P4	96.724	97.225	0.519
Purification flow (kg/s)		14.106	14.222	0.819
Temperature of flow from PHT to purification system (ºC)		265.745	265.841	0.036
Temperature of flow from purification system to PHT (ºC)		242.813	251.288	3.491
Bleed flow from PHT (kg/s)		6.626	5.134	-22.515
Feed flow to PHT (kg/s)		3.838	3.132	-18.405
TGVs opening (%)		50.151	60.821	21.276
Temperature of feedwater to SGs (ºC)	**SG1**	158.222	157.720	-0.317
	SG2	157.969	157.623	-0.219
	SG3	157.913	157.703	-0.133
	SG4	157.938	157.628	-0.197
SGs pressure (g) (kg/cm^2)	**SG1**	46.878	46.930	0.113
	SG2	46.663	46.817	0.330
	SG3	46.781	47.012	0.495
	SG4	46.804	46.886	0.176
Feedwater flow to SGs (kg/s)	**SG1**	237.741	239.172	0.602
	SG2	238.733	239.908	0.492
	SG3	240.663	239.546	-0.464
	SG4	239.212	239.457	0.102
Heat transferred in the SGs (MW)	**SG1**	504.059	509.532	1.086
	SG2	506.540	511.215	0.923
	SG3	510.583	510.335	-0.049
	SG4	507.217	510.378	0.623

Table 1 Comparison between the simulation results and plant measurements in steady state.

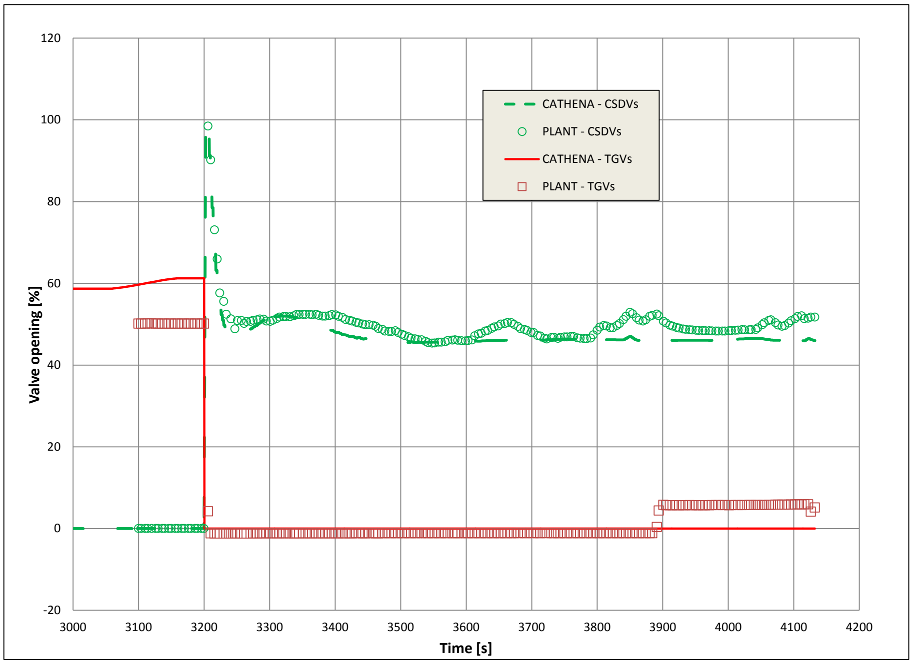

Figure 2 CSDVs opening and closing of TGVs.

Figure 2 shows that the simulated CSDV opening behaviour is consistent with plant measurement. After the turbine trip at 100%FP, CSDV fully open for 4 s (this is a process interrupt) and then return to their normal control mode.

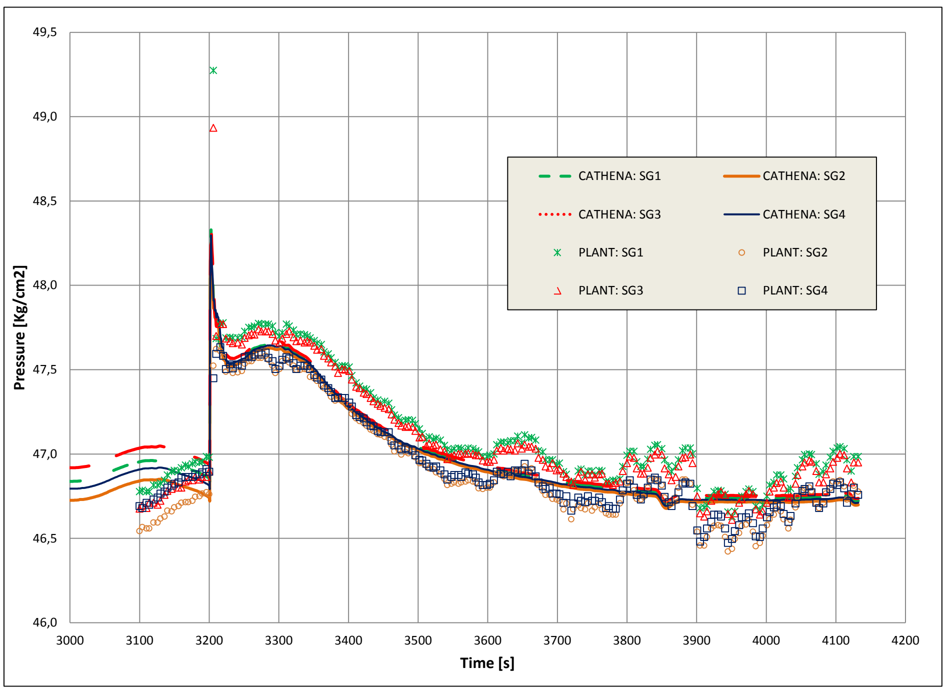

Figure 3 Pressure in secondary side of SGs.

Simulation reproduces very well the behaviour of SHT pressure (Figure 3) throughout the transient but not exactly during pressure excursion (the measured SG1 and SG3 pressures are higher).

Due to increasing SG pressure, the water temperature in the SG increases and degrades heat transfer from the PHT. This degradation causes the inlet header temperature (Figure 4) increases during the first seconds of the simulation.

The reduction of power, by the action of the reactor control system, reduces heat transfer from the fuel causing PHT cooling, as shown in Figure 4.

At approximately 3240s, the SGs feedwater temperature has not yet decreased (Figure 5), therefore the heat is not properly transferred to the SHT and a second temperature rise occurs in the inlet headers.

Comparing Figure 4 and 5 it can be seen that when the feedwater temperature drops (at 3300 s for the simulation and at 3350 s for the plant) the heat removed from PHT is increased which causes a reduction in headers temperature.

Later, at the plant, there are two feedwater temperature increases, at 3750 s and 3950 s, they produce a headers temperature rise, while in the simulation the feedwater temperature is constant which causes that headers temperature remains around 261 ºC.

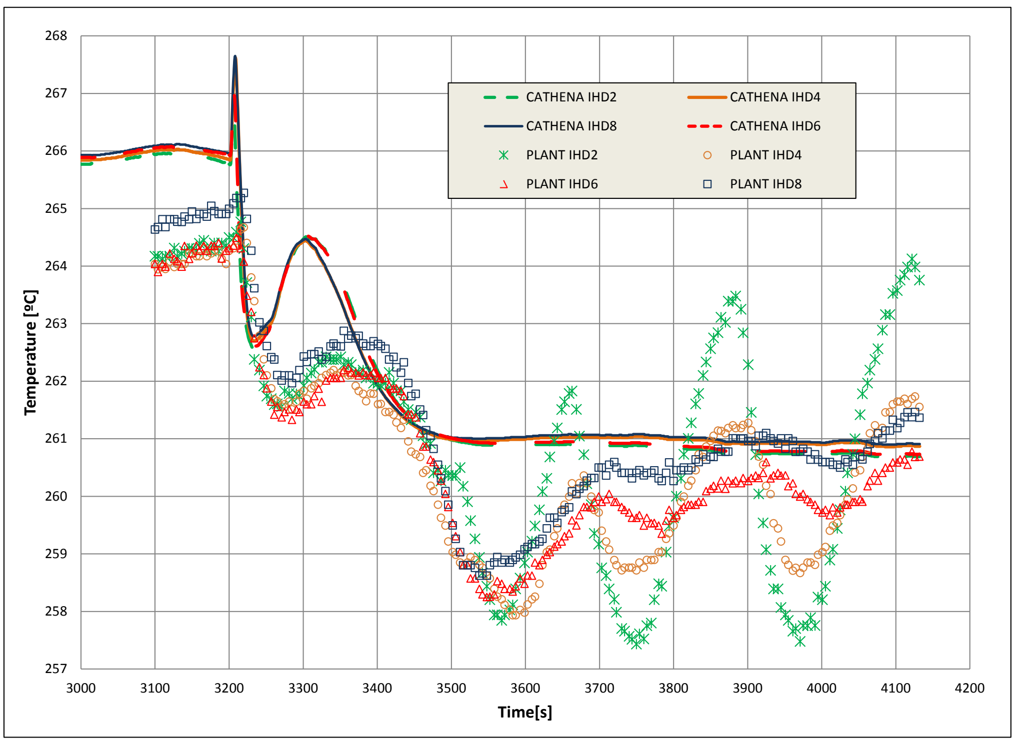

Figure 4 Inlet headers temperature.

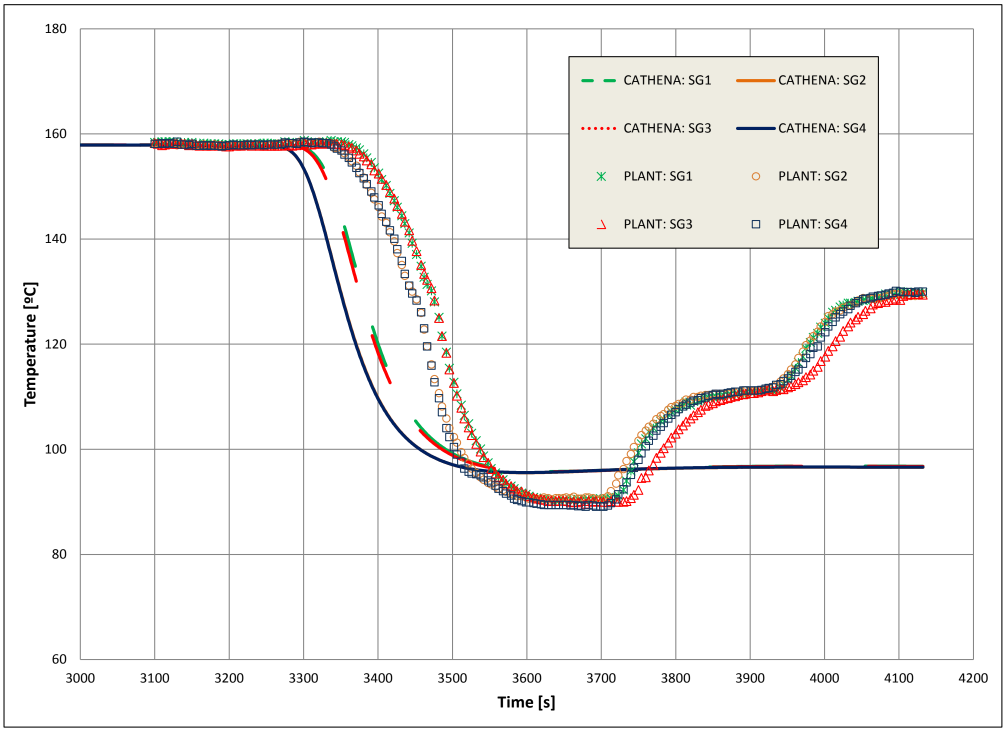

Figure 5 Temperature of feedwater to SGs.

The feedwater flow to SGs decreases from the 3200s, as shown in Figure 6.

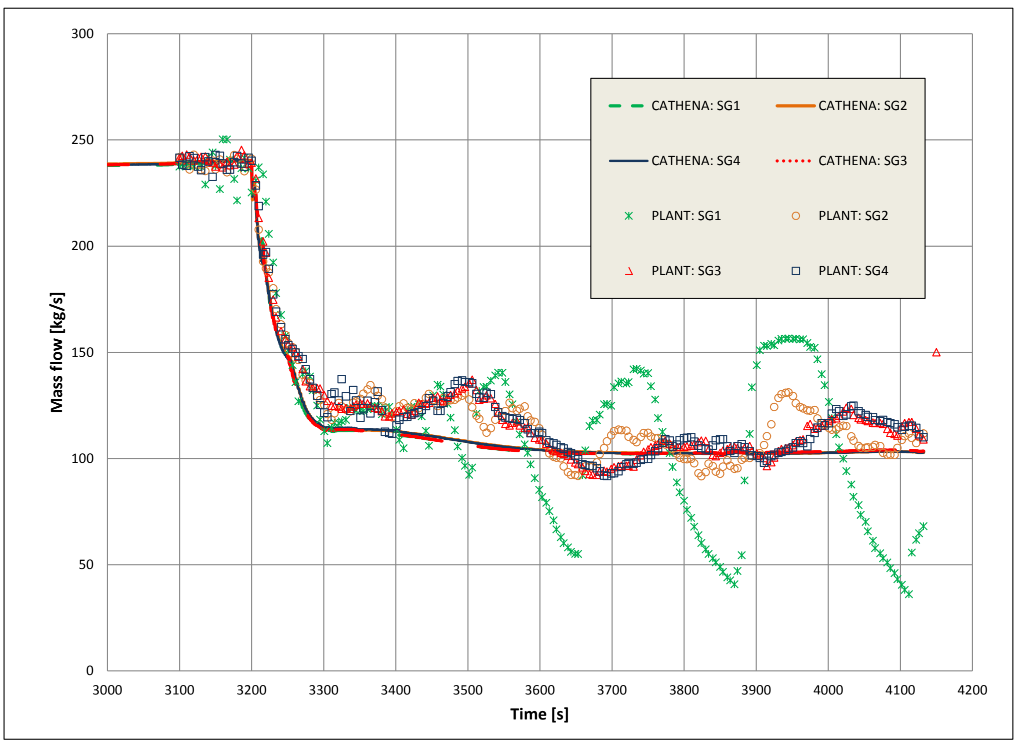

Figure 6 Feedwater mass flow to SGs.

Furthermore, the turbine trip interrupts preheating of feedwater to SGs. At the plant, the feedwater temperature decreases sharply from the 3300s (Figure 5), whereas the descent in the simulation starts to 3200s. This difference exists because the model interrupts all steam extractions, while in the plant the remaining steam allows to maintain the feedwater temperature a little longer.

Due to the existence of an integral steam generator preheater, the effect of a colder water supply causes a greater temperature gradient in the preheater between PHT coolant and the feedwater to SGs, which increases the heat transfer and causes the cooling of the inlet header water (Figure 4). Subsequently, the malfunction of the feedwater valves of SG1 and SG3 causes oscillations in the feedwater flow (Figure 6) and it also has an effect on the reactor inlet temperature (Figure 4).

In Figure 4, plant data and simulation results for core inlet temperature are shown. The general behaviour is similar.

The decrease in power and PHT coolant temperature causes a decrease of the volume. Pressurizer level and plant pressure drop initially. The model adequately represents the process (Figure 7).

SGs level plant data (Figure 8) indicates a more significant decrease than the calculated values, although the behaviour of the simulated variable is appropriate. The level drops because the set-point depends on the reactor power which is reduced by reactor regulating system. A notorious discrepancy between the simulation and the plant data is the SG level in the first 50 seconds. In general, all the simulations present these differences between the simulation and the plant about the SGs level, especially during fast transients. These discrepancies are due to both the level calculated by simulation as the measured level at the plant have uncertainties related to the existence in the SGs of a two-phase fluid which changes their conditions such that it is very difficult to predict during fast transient.

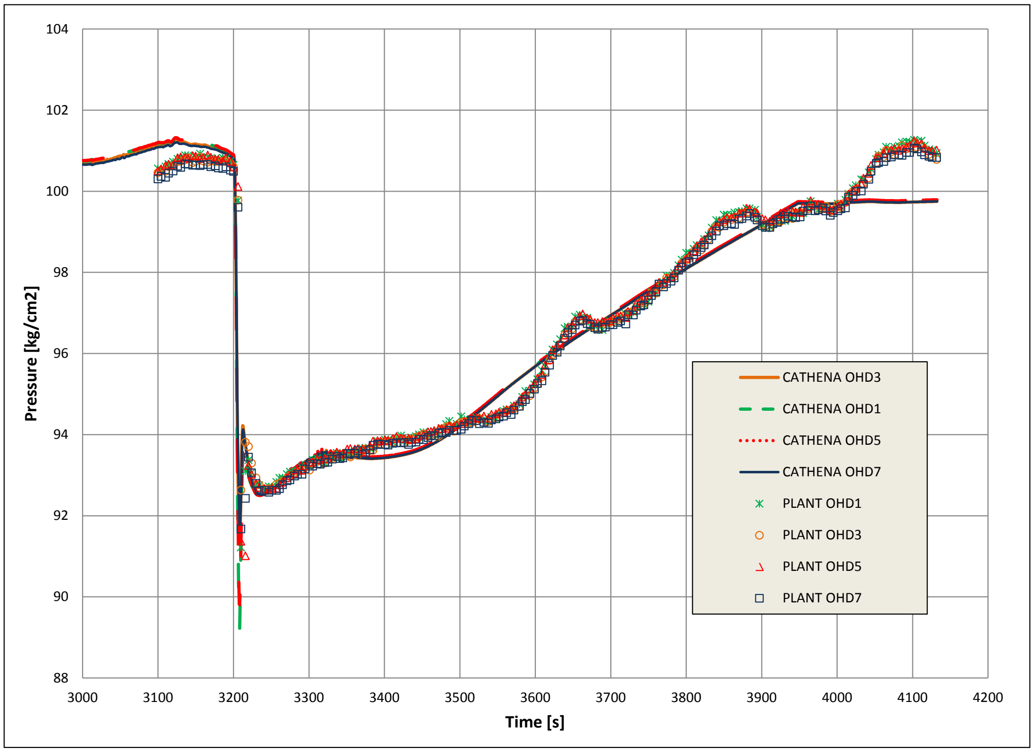

Figure 7 Outlet headers pressure.

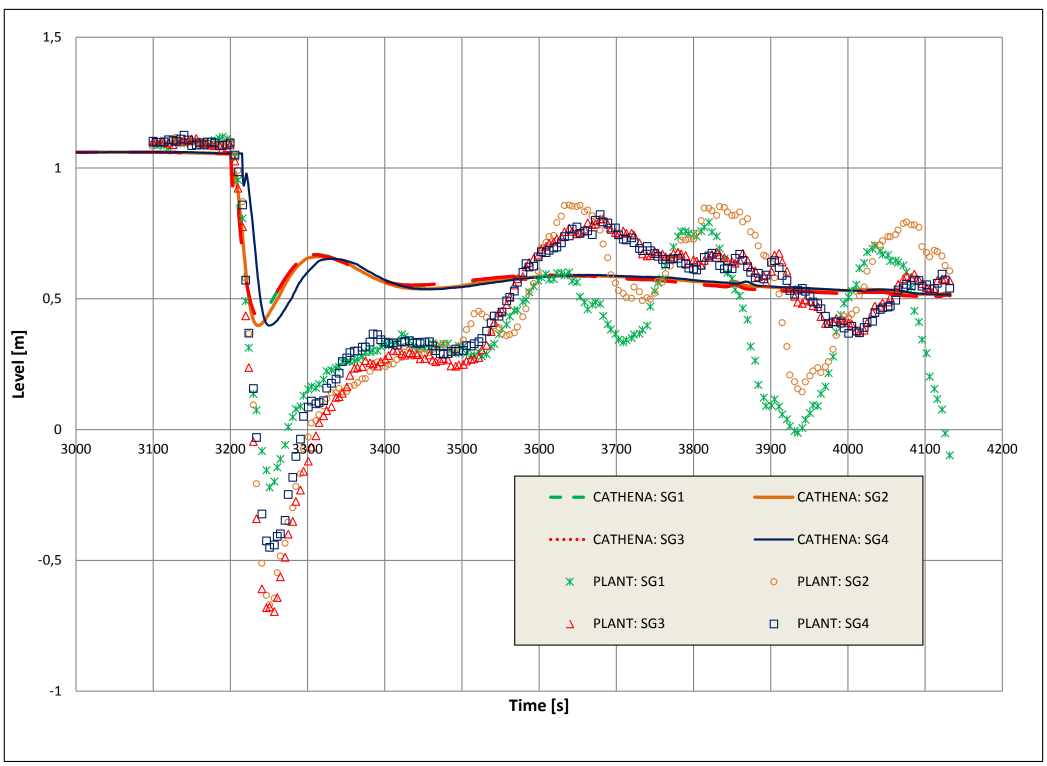

Figure 8 SGs level.

4. Conclusion

The CNE NPP model for CATHENA has involved an extensive work. Each relevant system for analyses to be performed is simulated and tested separately. Then, the system is incorporated to the entire plant model. Thus, the complete plant model is updated as required. When more details of any system are required to simulate a transient or an event, the model is modified in order to meet this new requirement.

At each stage, steady state comparisons at various powers and transient calculations are redone. Among the transients analysed to validate the model with respect to the SHT, turbine trips were simulated with or without CSDVs available and with spurious CSDVs openings that occurred during the life of CNE NPP. Some transients may be more useful from the point of view of quantity and quality of data than others, but all provide information and capacity to analysts to know the advantages and limitations of the model.

In this case, a turbine trip, the transient behaviour of the key variables is in reasonable agreement with the plant data. The values calculated of SGs level imply the need to take a rather large uncertainty (about 1 meter) when the reactor trip on SGs low level is considered.

It is also important to properly assess and set the channels void prior to the calculation of the transient. This implies that, in the case of a Safety Analysis, different plant configurations must be taken into account, for example: beginning of plant life with low reactor inlet temperatures and aged at higher core inlet temperatures. It is also necessary to perform sensitivity analyses for cases with low pressure in the outlet headers, among others.

5. References

[1] Hanna B.N., “CATHENA: A thermalhydraulic code for CANDU analysis. Nuclear Engineering and Design”, 180:113–131, 1998.