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THERMO-HYDRAULIC EXPERIMENTS FOR THE DEVELOPMENT OF A SYSTEM FOR IDENTIFICATION AND CLASSIFICATION OF TRANSIENTS (SICT)

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ABSTRACT

The safety of nuclear power plants has always been a concern when this technology is considered as an option for power generation. As a contribution to the improvement of its safety performance, a System for Identification and Classification of Transients (SICT) is being developed. This system is based in neural networks particularly Self-Organizing Maps and has as goal to assist the operation of nuclear plants. The development of this system has several phases and one of them is the demonstration of the capability of SICT to respond on time for transients being able to warn the operator. This demonstration will be achieved using experiments in a thermo-hydraulic facility – CT1 – in CDTN, having the SICT coupled to it. Before coupling the SICT with CT1 instrumentation it has to be trained to recognize different operational states possible in the installation. This training is performed using results of simulation of experiments with the RELAP5 code, in the same way as the SICT for the Nuclear Power Plant shall be preliminarily trained using results of simulations. This paper presents the description of such facility, with the coupled SICT, the carried out experiments, as well as, their simulations with RELAP5 and the overall performance of SICT.

1. INTRODUCTION

Artificial Neural Networks – NN have been used for several reasons in nuclear reactors, to evaluate signal failures [1], plant diagnostics[2], performance evaluation[3] and identification and classification of transients [4][5]. Currently it is being under development a System of Identification and Classification of Transients – SICT based on a NN to follow the operation of an innovative nuclear reactor [6]. Distinguishing characteristics of SICT are the need of only few signals from the reactor and the use of a particular type of NN called Self-Organizing Maps – SOM [7].

This paper presents the current status of the use of thermo-hydraulic experiments as part of the development of SICT.

One of the steps in the development of a prototype for identification and classification of the operational state of a nuclear reactor is the demonstration of its capability of providing relevant information in real time, through collection, processing and presentation of data to the facility operators.

To reach that goal, after the definitions of SICT for the reference reactor, about the same number of signals from an thermo-hydraulic experimental facility will be monitored and presented to SICT, which will be coupled to this facility. To accomplish this task it is being used the thermo-hydraulic facility – CT1 in CDTN.

SICT prototype must be initially trained using signals representing transient and in different states of steady state regimes of CT1. After being trained the prototype is then connected to the reactor or facility to perform its function, i.e., to identify on line its current operational status. The data for SICT training will be those obtained through simulations with RELAP5 code.

This procedure is similar to that proposed to the development of the SICT for the reference reactor, which would be trained with data obtained from simulation, making the system able to recognize the operational status of the reactor afterwards.

The current version of SICT is being developed using C++ and contains two main parts, one that consists of the artificial neural network using SOM and another that is responsible to collect, preprocess and supply the data to the NN/SOM.

2. THE TEST FACILITY CT1

CT1 is a closed thermo-hydraulic circuit that uses water as fluid and capable of heat generation and extraction with pressures in the range from 0.1 to 1.5 MPa. In this circuit experiments can be accomplished for the determination of thermo-hydraulic parameters and phenomena as: heat transfer coefficients, pressure drops and critical heat flux. Those experiments can be carried out in monophasic or two-phase flow regimes in different geometries: tubular, annular or in rod bundles.

A detailed description of CT1 was published in 1975 [8], and its main components, following its adaptation for these experiment series, are briefly described:

- Tests Section, composed of a tube of steel that is heated up by effect Joule through a rectifier with maximum power of 120 kW;
- Pressurizer, formed by a cylindrical vase with resistance interns to compensate the losses of heat. The maximum pressure of work is 1.5 MPa;
- Heat Exchanger, whose function is to remove the heat given to the fluid in the test section. It has a maximum capacity of 300 kW and
- Main Pump, with maximum flow of 1.33 kg/s and maximum head of 0.32 MPa.

Other ancillary equipments are:

- Electric Power Rectifier, which can be controlled by a computer to supply up to 120 kW;

- Water Deionization System which stores deionized water to fill CT1 before a test series;

- Refrigeration Tower that dissipates to atmosphere the heat transferred from the circuit to the heat exchanger;

- Data Acquisition System which converts the signal from the analog instrumentation to digital form and delivers it to the computational system.

3. EXPERIMENTAL PROGRAM

In order to achieve the proposed goals the CT1 will be operated in steady state conditions as well as in slow and fast transients of power and pressure, whose data will be processed by SICT.

3.1. Steady State Experiments

The different steady states differ amongst themselves due to the different electric power levels supplied to the test section or different system pressures, flow and entrance temperature, which will be maintained constant. Each experiment of stationary state at different potency levels should be maintained until obtaining the stable conditions.

3.2. Transient Experiments

The main transients envisaged to be carried out in CT1 are:

- Power change in ramps: these tests will change the power in 10% up or down at a rate of 5%/min;

- Power change in step: these tests will change the power in 10% up or down in shortest time allowed by the electric supply system;

- Loss of cooling through the isolation of the heat exchanger;

- Depressurization through blow down of the pressurizer by its isolation valve;

- Abrupt power change upwards and downward of 70% and

- Loss of pump power.

4. RELAP5 SIMULATION OF THE EXPERIMENTS

The simulation of CT1 experiments with RELAP5 has two main reasons: to help in experimental operation planning and the most important: to follow the same methodology for the development of SICT to CT1 as will be used to development of SICT to a nuclear reactor, i.e., use of computational simulation data to train the neural network. Therefore a nodalization of CT1 was developed and tested using RELAP5. The final schema of this nodalization is presented in Fig. 1.

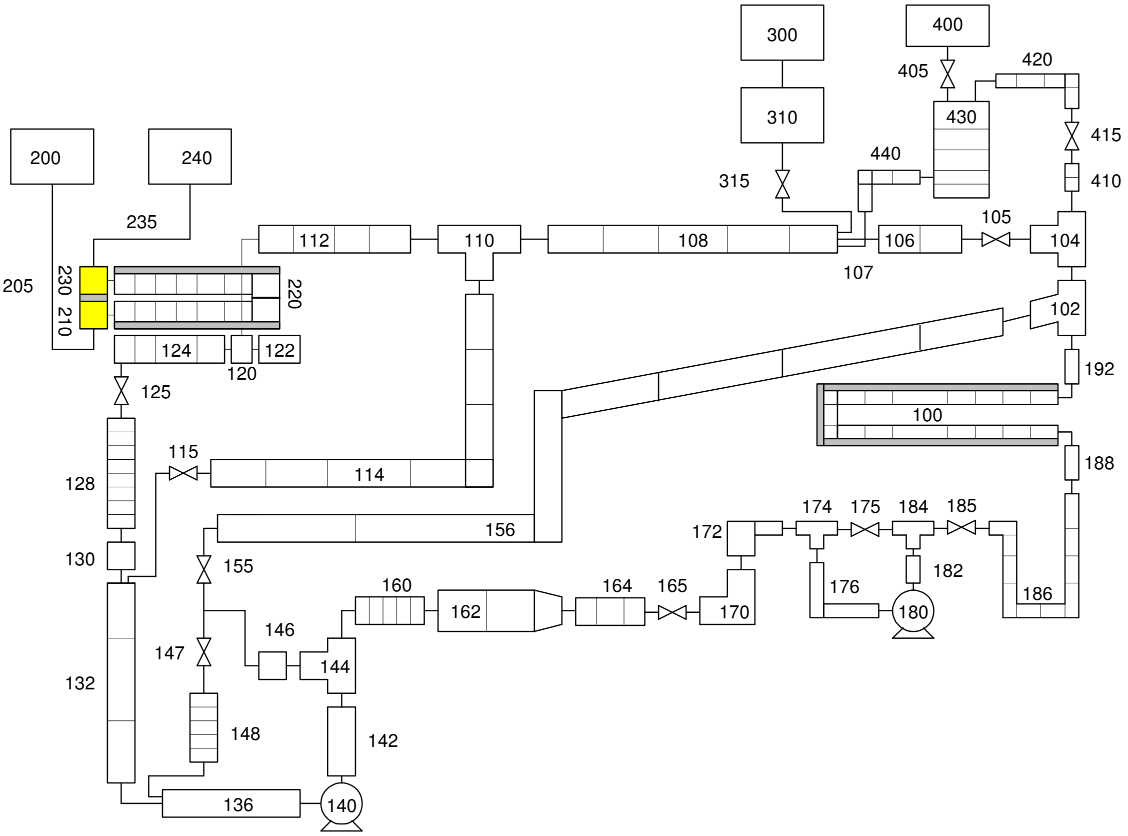

FIGURE 1. RELAP5 Nodalization of CT1

After the commissioning phase of CT1 the input data of this nodalization was adjusted to provide results closer to those measured during the operation of the facility. A first experiment was simulated with RELAP5 and carried out in CT1. Fig. 2 presents a comparison of the experimental and calculated power and Fig. 3 shows the comparison of calculated and experimental test section inlet and outlet temperatures.

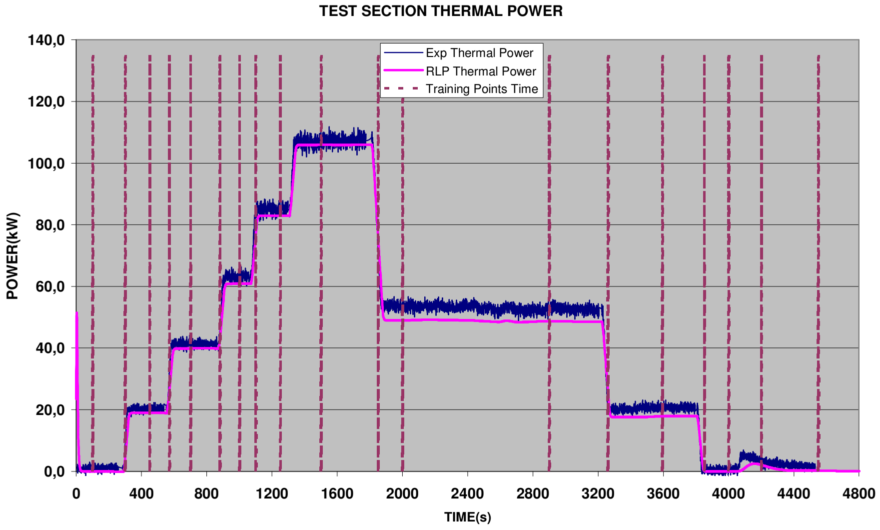

FIGURE 2. Comparison of Experimental and Calculated Thermal Power in the Test Section

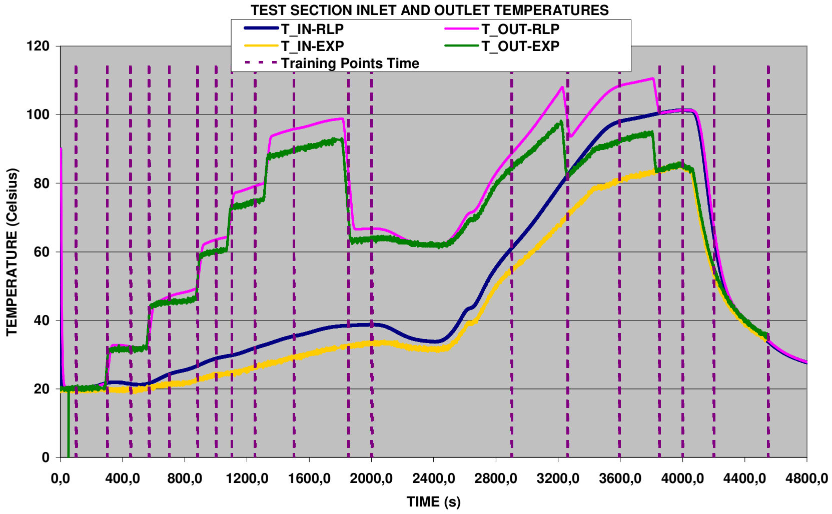

FIGURE 3. Comparison of Experimental and Calculated Test Section Temperatures

These results show a good agreement of the calculated and experimental thermal power in the test section and also that the temperatures show a similar behavior although their values can have differences of till 20K.

5. THE SYSTEM FOR IDENTIFICATION AND CLASSIFICATION OF TRANSIENTS - SICT

The SICT that was used with experimental and calculated data was trained with two sets of five instants taken from RELAP5 results corresponding to 19 conditions marked by the vertical lines in Figs. 2 and 3. The training data consisted then of 38 sets of 15 parameters. The parameters were 8 measured temperatures, the test section average temperature, mass flows in primary and secondary sides, 2 pressures, the thermal power and an averaged derivative of the thermal power. The training consisted of 120000 epochs.

The neuron weights - **W** were changed, approaching the input data **X,** during the learning phase using a neighborhood kernel, N(i, d), dependent of the epoch evolution – **i** and of the geometric distance **-d** of a neuron to the winning neuron, as shown in eq. (1). This neighborhood kernel decreased linearly with the epoch evolution and with distance. As the epochs increased it circumscribed the area that could still be changed. At he beginning the distance from a neuron to the winning neuron that could have its weights adapted was around 0.9 of the maximum distance among the neurons and after around 90000 epochs only the winning neuron would be adapted.

$$\mathbf{W_n^{i+1} = W_n^{i} + N(i, d)^{*} (X^{i} + W_n^{i}).} \qquad \mathbf{(1)}$$

The developed SICT supports different map geometry: hexagonal map with hexagonal cell, squared map with squared and triangular cells and triangular map with triangular cell. The results presented in this paper were obtained using a hexagonal map with hexagonal cell, as shown in Fig. 4.

6. CURRENT RESULTS

Fig. 4 presents the map configuration after 120000 epochs of learning. As described before each vertical line in Figs. 2 and 3 provided 2 input data sets. These set represented similar condition and are enclosed by different lines. It can be observed that the transients of power ramp up were gathered at the right upper part of the map while the power ramp down were at opposite position at the lower left part. The steady state condition were at the central part of the map separating the power transients and at le lower part were gathered the slow transients due to isolation and recuperation of the heat exchanger. Other information in this figure is represented by the colored solid lines separating the cells; they show regions of high distances between the weight of the adjoining cells, i.e., they delimitate strongly different regions and we can observe that they are again emphasizing the discrimination of different types of transients and steady states.

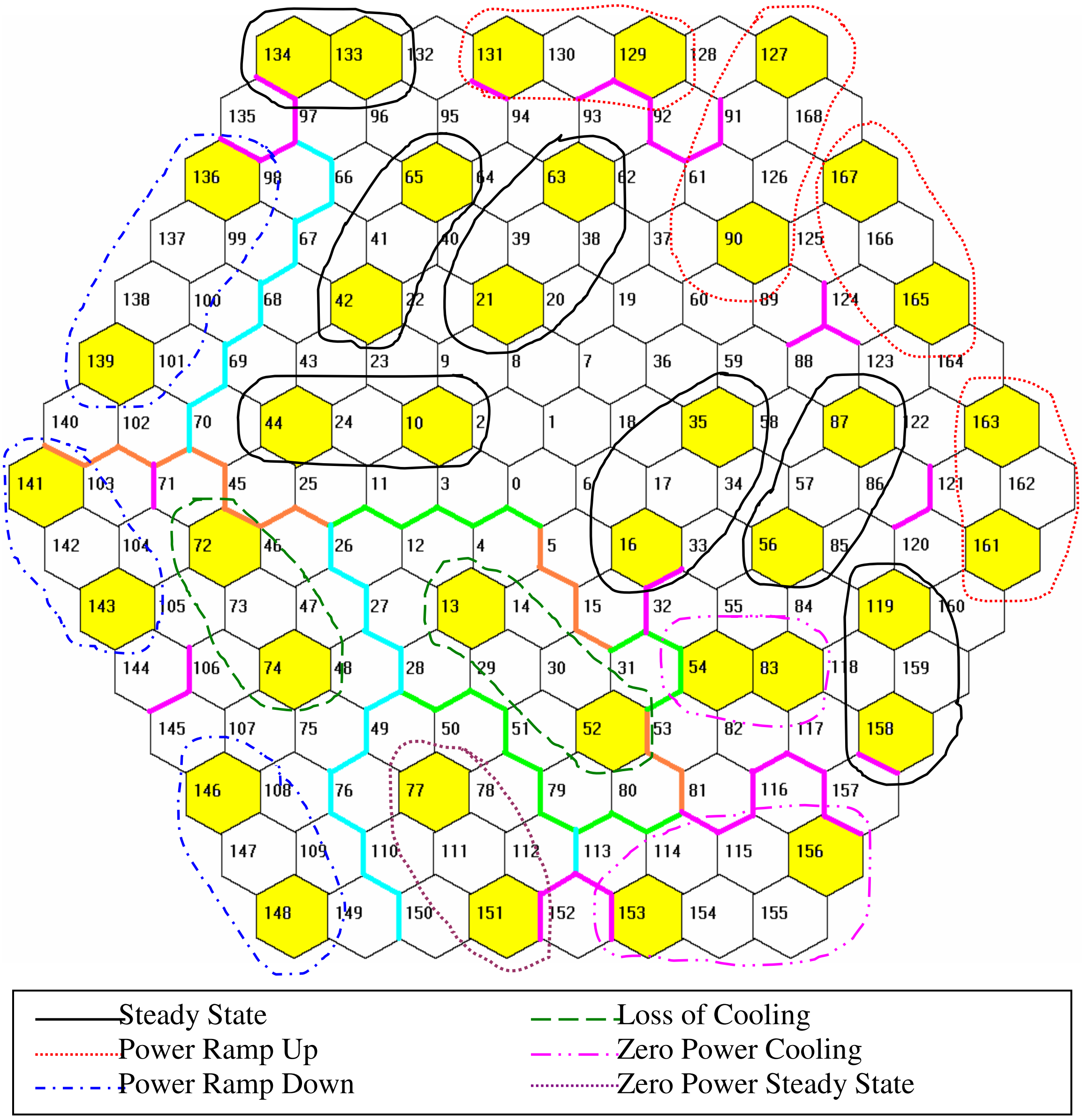

FIGURE 4. Mapping of Input Conditions in SICT Screen after Learning

After the learning phase SICT was run using the data of whole period - 0 to 4800s - of simulation and was run also with the available experimental data. The RELAP5 data fitted every yellow cell in the map and followed the all conditions correctly. The experimental data fitted most of the yellow cells but SICT failing mainly in recognizing the power ramp down transients, they seamed to be allocated in the left lower part of the map, which is a region more connected to slow transients. Many sets of experimental and calculated data are mapped to cells near 2 different regions what make it difficult to identify if it is a steady state or a specific transient,

7. CONCLUSIONS

A first achievement was the planning, adaptation and commissioning of the experimental facility – CT1, which is now available to operate to provide steady state and transient conditions to the development of SICT.

Another achievement was the development of a first version of SICT that can run continuously processing experimental data.

The results obtained by processing the presented experiment shows some points that still must be improved. The preprocessing of experimental data must be improved, since they present a high error band if compared with the training and calculated data (Fig. 2). The discrimination of the map has to be improved to allow identification of the operating condition; investigation of maps with more cells and of the LVQ can lead to a significant improvement.

REFERENCES

1. "A. Multiple-Failure Signal Validation in Nuclear Power Plants using Artificial Neural Networks," *Nuclear Technology*, **v. 113**, pp.368-374 (1996).
2. "Symptom Based Diagnostic System for Nuclear Power Plant Operations Using Artificial Neural Networks," *Reliability Engineering and System Safety*, **v. 82**, pp. 33-40 ,(2003).
3. "Use of artificial neural networks to analyze nuclear power plant performance," *Nuclear Technology*, **v. 99**, pp.36-42, (July 1992).
4. "Evaluation Test of Event Identification Method Using Neural Network at Kashiwazaki Kariwa Nuclear Power Station Unit No.4," *Journal of Nuclear Science and Technology*, **v. 33**, pp. 439-447, (1996).
5. "Application of Neural Networks to Connectionist Expert System for Transient Identification in Nuclear Power Plants," *Nuclear Technology*, **v. 102**, pp. 177-181, (May 1993).
6. B. D. Baptista F., A. C. O. Barroso, "Identification of IRIS Reactor Transients with Self-Organized Maps," *Proceeding of International Conference on Global Environment and Advanced Nuclear Power Plants - GENES4/ANP*, Kioto, 2003.
7. T. Kohonen, *Self-Organizing Maps*, Springer, Berlin Germany (2001).
8. A. M. Souza, K. Colares, *Descrição Final do Circuito Térmico N$^{\underline{o}}$ 1*, NUCLEBRAS/DTD/IPR, Belo Horizonte - Brasil (1975).