Computational Intelligence Approaches for Parametric Estimation and Feature Extraction of Power Spectral Density

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Abstract

This paper reports an early progress of a feasibility study of a computational intelligence approach to the enhancement of the accuracy of flow measurements in the framework of a current cooperation between Tecnatom s.a. in Madrid and the OECD Halden Reactor Project in Halden. The aim of this research project is to contribute to the development and validation of a flow sensor in a nuclear power plant (NPP). The basic idea of the current project is to combine the use of applied computational intelligence approaches (noise analysis, neural networks, fuzzy systems, and wavelet etc.) with existing traditional flow measurements, and in particular with cross correlation flowmeter concepts. The design of possible algorithms based on computational intelligence approaches will be modified during the tests of a real NPP.

Keywords: Neural fuzzy systems, AI, Parametric estimation, Power spectral density, Flow measurements, Nuclear power plants (NPPs).

1 Introduction

Safe and reliable operation of nuclear power plants (NPPs) benefits from R&D advances and related technical solutions. The OECD Halden Reactor Project, a joint undertaking of national organizations in 20 counties sponsoring a jointly financed programme under the auspices of the OECD Nuclear Energy Agency, is an international network fostering these advances with programmes devised to provide answers in a direct and effective manner. The Project's strong international profile and solid technical basis represent an asset for the nuclear community at a time in which maintaining centers of expertise at accessible cost becomes increasingly important.

In addition to the joint programme work, a number of organizations in the participating countries execute their own development work in collaboration with the Project. These bilateral arrangements constitute an important complement to the joint programme and normally address issues of commercial interest to a participant organization or group of organizations [10].

This paper presents a feasibility study of a computational intelligence approach to the enhancement of the accuracy of flow measurements, which is a current cooperation between Tecnatom s.a. in Madrid and the Halden Reactor Project in Halden (2001-2002) [4].

The example application described in this paper, i.e., the flow measurement estimation based on noise analysis, is an ideal candidate for the application of computational intelligence techniques such as artificial neural networks (ANNs) and fuzzy systems (FSs). The aim of this research project is to contribute to the development and validation of a flow sensor. Flow measurements, classically based on Venturi's principle, are subject to known accuracy problems, especially in the presence and build-up of fouling in the Venturi constriction. To obtain more accurate flow measurements, computational intelligence techniques can be applied [9]. The idea is to develop a "virtual flowmeter" based on neural cross-correlation analysis of signals obtained from sensor pairs placed at spatially separated locations along the subject pipe. Inputs to the neural virtual flowmeter will also include other plant measurements that have an influence on the velocity profile of the fluid in the pipe, e.g., temperature and pressure measurements. Feature extraction from PSD (power spectral density) spectra is also considered as a promising approach for facilitating the neural cross-correlation analysis. A combination of ANNs and Wavelet Decomposition techniques is a strong candidate for this task.

ANNs and FSs based signal-processing tools and Wavelet based techniques have been developed and tested at the Halden Reactor Project (HRP) during several years of study and application. Of particular interest for this project are the neuro-fuzzy signal validation and reconstruction tool PEANO [2], and the wavelet-neuro transient classification tool ALADDIN [7].

In the current project on enhancing accuracy in flow measurements, besides the above-mentioned techniques available at HRP, fuzzy systems [8] will be further coupled with ANNs for parametric estimation and feature extraction of PSD. Due to the finite resolution of any measuring instrument, appropriate quantization, whose coarseness reflects the limited measurement resolution, is inevitable whenever a variable represents a real-world attribute. A fuzzy system can help to use linguistic labels to describe each of the inputs and outputs of flow measurements, and further to extract some particular features by using measurement date. It is expected that the results obtained in the project would be used for the development of a new type of sensor that will provide better estimates of critical process parameters. The extrapolation of the results for making measurements in a real nuclear power plant will be demonstrated in the final project. The physical validation of the development of the project will be carried out in an experimental facility that will be adapted to analyse water flows.

2 Objectives and Tasks

One of the main intentions of the Halden Reactor Project during the 2000-2002 period is to enhance the Project's abilities in identifying and rectifying problems that affect the thermal performance of NPPs. This would be achieved through the study and implementation of new techniques with an emphasis on practical applications of these techniques. The main objective of this project is to study the applicability of computational intelligence approaches for flow measurements in NPPs.

As introduced in [5], one of the primary objectives of the power plant industry has long been the efficient operation of plant systems, thus reducing the cost of electricity. The operating thermal power of a nuclear reactor is limited by the Nuclear Authority licensing requirements. Therefore, the thermal power of the plant should be determined very accurately. The feedwater flow rate is one of the major quantities used in determining the thermal power. Feedwater flow signal is also one of the important parameters used for steam generator water level control in pressurized water reactors (PWRs) and reactor vessel water level control in boiling water reactors (BWRs). This flow rate is measured by installed Venturi meters. The pressure drop across the Venturi tube, using pressure taps at the inlet and the throat, is measured and is related to the flow rate in the piping.

Venturi flow measurements are subject to known accuracy problems, mainly originating from the gradual build-up of fouling in the Venturi constriction. A *smaller* constriction leads to an overestimation of actual flow, and consequently to an overestimation of the produced thermal power. To stay within authority limits, reactor utilities are therefore forced to derate their plants.

Venturi meter fouling is "the single most frequent cause" for derating in PWRs. A derating of 1% in an 800-MW (electric) unit will cost the utility about $10 000/day given a unit cost of electricity of $0.05/kW.h [1, 5]. In the current project, we aim at enhancing the accuracy of flow measurements, which is, indeed, to reduce as much as possible the derating induced by measurement uncertainty.

The core of the proposed virtual flowmeter will be based on the actual kernel of PEANO, which will be modified for applications in the frequency domain (noise).

The proposed tasks to be carried out within the project related with the measurement of feedwater flow are briefly described in the following subsections.

- Detailed definition of tasks and objectives
- Experimental installation conditioning
- Data acquisition system start-up

- Redefinition of algorithm and analysis
- Preliminary tests and analysis
- Final tests realization and analysis
- Extrapolation study.

2.1 Detailed Definition of Tasks and Objectives

The first activity of the project is to analyse the actual available feedwater flow measures of a nuclear plant. This is mainly for using standard sensors after a detailed study of different possible sensors used in feedwater measures based on noise analysis.

2.2 Experimental Installation Conditioning

Following the initial description of the project in the first stage, the physical changes that will have to be carried out in a real plant will be further specified and implemented. Because of the objective of the project, a new data acquisition system seems necessary. This system will include online Fourier analysis capabilities and be flexible enough to allow different scanning rates.

2.3 Data Acquisition System Start-up

It is an essential task of the project to obtain good measurements, which makes the start-up activities of the new data acquisition system. A wider range of commercial tools will be tested for selecting a first set of data at the beginning of the project for the off line activities.

2.4 Redefinition of Algorithm and Analysis

To obtain only one output, namely the feedwater flow, the actual algorithms of PEANO will be modified. The objective of these modifications is to adapt PEANO and to obtain a "virtual flowmeter." The modified algorithm of PEANO will be optimized for the interpretation of PSD information. It will be obtained from the noise in two different parts of a pipe (Fig. 1).

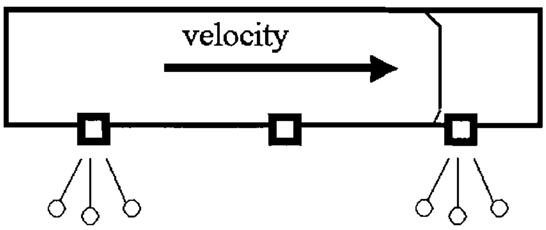

Figure 1: Noise in the two different parts of a pipe

2.5 Preliminary Tests and Analysis

An in-depth analysis of signal selection, training data and tests will be carried out, which will serve the basis for the definition of the final tests.

2.6 Final Tests Realization and Analysis

A detailed test and implementation will be realized in an experimental facility at Tecnatom under this cooperation.

2.7 Extrapolation Study

In order to apply the "virtual flowmeter" developed in the project to a real nuclear power plant, the extrapolation of the obtained results of the project will be further investigated. The necessary steps for making flow measurement tests in a nuclear power plant to validate the virtual flow instrument need to be defined.

3 The Role of Computational Intelligence Approaches in Flow Measurement

Until now, there has been a lot of progress in the development of signal processing techniques for the estimation of actual feedwater flow rates. One of the highlights among these advances has been the use of neural network based approaches which have been showing very positive prediction capabilities (e.g., [1-3], [5]). In this work, a neural network is used as an essential component and additional signal processing techniques such as robust training concept or filtering are used as the accuracy enhancement method or the load reducer of a neural network [3].

The basic idea of the current project is to combine the use of applied computational intelligence approaches (noise analysis, neural networks, fuzzy systems, and wavelet etc.) with existing traditional flow measurements methods, and in particular with cross correlation flowmeter concepts [11, 12].

Possible roles of computational intelligence techniques can be seen in the following diagram (Fig. 2).

System identification deals with the problem of building mathematical models of dynamical systems based on observed dada from the systems [6]. In this respect, the current project focuses on a feasibility study of applied computational intelligence approaches to the parametric estimation (determining p1, p2, p3...) for a model of calculating PSD and to the feature extraction before the flow calculation.

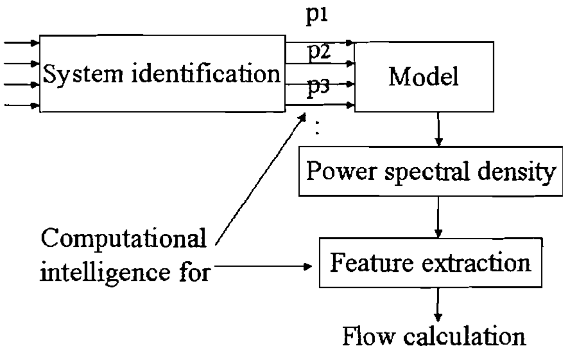

Figure 2: The role of computational intelligence approaches in the project

The development of a "computational intelligent" cross correlator will be the other main focus of this project. The preferred method in the literature for fluid velocity estimation by cross correlation analysis, is based on the computation of the cross correlation of the up-stream and down-stream signals, and on the location of the maximum of the cross correlation function, which indirectly indicates the time-delay and the velocity of the fluid. A different approach is based on delaying the up-stream signal by a delay time τ, until the mean square difference between the two signals reaches a minimum.

A third focus of this project will be on the use of computational intelligence techniques for the integration of direct flow estimates (e.g., the output of the above mentioned techniques) with other sources of "flow related" information from other plant signals (e.g., temperature, pressures, vibrations, noise, etc.), which could be possibly used to achieve higher overall accuracy performance.

Results of any theoretical study will have to be tested in a real plant. As a consequence, the design of possible algorithms based on computational intelligence approaches will be modified at the early stage of the project.

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