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# Time–scale BWR stability analysis using wavelet-based method

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**Abstract**

This paper describes a methodology based on wavelet techniques for instability analysis in BWR. The Continuous Wavelet Transform and Multiresolution Analysis using Discrete Wavelet Transform were applied for decomposition of the original signal. This method allows to analyze stationary signals and highly non-stationary signals in the time–scale plane. The results using this method were compared with classic method based on Short-Time Fourier Transform. The methodology was tested analyzing two power instability events: Laguna Verde Unit 1 and case 5 of Forsmark stability benchmark.


*Keywords:* Wavelet-methods; BWR stability; Decay Ratio; Forsmark stability benchmark; Laguna Verde stability event; Time-scale transform

## 1. Introduction

The estimation of the stability parameters of a Boiling Water Reactor (BWR) has been the object of the development of several methodologies using different techniques in order to estimate the fundamental frequency and Decay Ratio. Some of them are only applicable when the signal is stationary (Verdu et al., 2001), and other ones when the signal is non-stationary using short-time windows that provide reliable results. Navarro-Esbri et al. (2003), studied the natural frequency time dependence with two different tools: Short-Time Fourier Transform (STFT) and Time Dependent Power Spectral Density (TDPSD) based on splitting the signal in short segments with high degree of overlapping. Their results show that STFT provides better accuracy, however, the TDPSD is less sensitive to the noise in the neutronic signal. An autoregressive method (AR) was used by these authors to estimate the Decay Ratio (DR). One of the most important disadvantages in all these methods is that they involve many calculations, however, they could be easily implemented into an on-line stability monitor.

Blazquez and Ruiz (2003) analyzed the Laguna Verde instability event in the time and frequency domains. In the frequency domain, the transition from stability to instability was detected when the real pole of the power spectrum density (PSD) almost vanished. In the time domain, AR method does not show a transition, but indicates how the reactor loses its stability progressively.

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Tambouratzis and Antonopoulos-Domis (2004) presented a methodology based on wavelet Multiresolution Analysis (MRA) with a selective removal coefficient to estimate the system parameters during transient operation. Wavelet analysis was used to separate the signal into two parts: (1) the expectation value and (2) non-stationary noisy signal. After this decomposition, the inverse wavelet transform allows the estimation of the transient part of the signal. These authors show an application for BWR stability using numerical experiments, i.e. real BWR signals were not used.

A recent paper of Espinosa-Paredes et al. (2005) explored the wavelet techniques (Daubechies, 1992) as a new alternative for transient instability analysis. Their key observation is that stability depends on several variables such as control rod pattern, void fraction, burnup, inlet mass flow, among others, which are non-stationary signals and in traditional methods analysis (e.g., Fourier transform; Gabor, 1946) these variables are considered constant when stability parameters are computed. Other application of wavelet method in nuclear power plant was presented by Park et al. (2004), using this technique for noise-reduction to water-level controller in PWRs.

In this paper a wavelet-based method was used to estimate the linear stability parameters and we apply this methodology using neutronic power signal of two BWRs: Laguna Verde and Forsmark. The methodology takes into account the Continuous Wavelet Transform (CWT), Discrete Wavelet Transform (DWT), and the Short-Time Fourier Transform (STFT) was used as a complement tool. This method allows to analyze stationary signals and highly non-stationary signals in the time–scale plane. In the first part of this paper a brief theoretical background of the different methods is presented, in the second part we describe the methodology based on wavelet method and finally we show its application to two real BWR signals.

## 2. Theoretical models

This section presents a mathematical description of different methods used in this paper. One of the methods is based on the time–frequency transformation that compares the signal with a family of functions where the oscillations increase when the frequency under consideration increases, however, the limitation is that the time support remains constant. The other one is a time–scale method that compares the signal from a collection of elements where the numbers of oscillations remain constant when the time support decreases. In this way, the transformation can detect discontinuities which are well located in the signal. Both methods are briefly described in the next subsections.

### 2.1. Time–frequency transform

One of the most important time–frequency transformations is the Short-Time Fourier Transform (STFT). It uses a windowing technique to analyze a small section of the signal in discrete-time, and it is defined by (Gabor, 1946):

$$X_l(k) = \sum_{n=0}^{N-1} w(n)x(n+lH)\mathrm{e}^{-jw_k n}; \quad l = 0, 1, \ldots \tag{1}$$

where $w(n)$ is a smoothing window and $H$ represents the window size. This window measures the evolution in time of the spectral content of $x(t)$. The term $w_k (=2\pi f_k/f_\mathrm{s})$ is the frequency of the $k$th bin expressed in radians and normalized by the sampling frequency ($f_\mathrm{s}$). Spectra for each of the $l$th frames are estimated over $N$ frequency bands.

The density of energy denoted as $P_\mathrm{s}$ is obtained by:

$$P_\mathrm{s} = |X_l(k)|^2 \tag{2}$$

It is called a *spectrogram* and measures the energy of the signal in the time–frequency. This transform was considered by Navarro-Esbri et al. (2003) in their work to study frequency contents of a signal.

### 2.2. Time–scale transform

A wavelet $\psi$, is a function used in the time–scale transformations, where a comparison of the signal is done among a collection of elements where the number of oscillations remains constant when the time support (time where mother