AN OVERVIEW OF WAVELET TRANSFORMS APPLICATION IN POWER SYSTEMS

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Abstract – Wavelet transform has received great attention in power community in the last years, because are better suited for the analysis of certain types of transient waveforms than the other transforms approach. This paper presents a descriptive overview of the wavelet transform applications in power systems. The main publications carried out in this field have been analyzed and classified by areas. A list of 116 references is also provided.

Keywords: Signal processing, wavelet transform, time-frequency analysis, power systems.

1 INTRODUCTION

Wavelet transform (WT) has been introduced rather recently in mathematics, even though the essential ideas that lead to this development have been around for a longer period of time. It is a linear transformation much like the Fourier transform, however it allows time localization of differences frequency components of a given signal; windowed Fourier transform (STFT) also partially achieves the same goal, but the fixed width windowing function is a limitation. In the case of the wavelet transform, the analyzing functions called wavelets, will adjust the time width to the frequency in such a way that high frequency wavelets will be very narrow and lower frequency ones will be broader. There are two main approaches to present wavelet theory: the integral transform approach (continuous time) and the multiresolution analysis (MRA)/filter bank approach (discrete time).

Several works have been developed in many areas with the aim of this tool, specially, in the last ten years have been met the potential benefits of applying WT to power systems due to, among other, the interest in analyzing and processing the voltage-current signals in order to make a real time identification of transients in a fast and accurate way.

The aim of this paper is to provide a descriptive overview of the wavelet transform applications in power systems to those who are novel in the study of this subject. For this purpose, the main publications carried out in this field have been analyzed and classified by areas. For space reasons, a group of 116 references have been selected by the authors of this paper's criteria, choosing those more representative of a certain area either for their contributions or continuity of a line of investigation.

2 APPLICATION OF WAVELETS IN POWER SYSTEMS

In the mainstream literature, wavelets were first applied to power system in 1994 by Robertson [17] and Ribeiro [4]. From this year the number of publications in this area has increased as Fig. 1 shows.

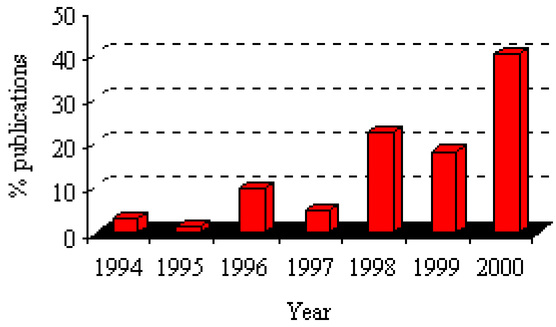

Fig. 1: Evolution of wavelet publications in power system.

The main focus in the literature has been on identification and classification methods from the analysis of measured signals, however, few works use wavelet transform as an analysis technique for the solution of voltages and currents which propagate throughout the system due, for example, a transient disturbance.

The most popular wavelet transform applications in power systems are the following:

- Power system protection
- Power quality
- Power system transients
- Partial discharges
- Load forecasting
- Power system measurement

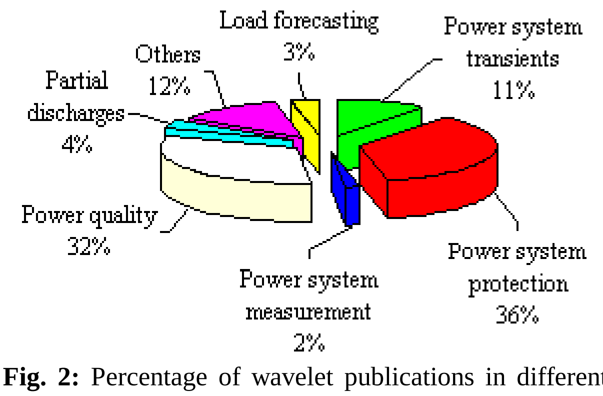

Fig. 2: Percentage of wavelet publications in different power system areas.

Fig 2 shows the percentage of publications in each area; the areas in which more works have been developed are the protection and power quality field. Next sections present a general description of wavelet applications in the selected areas of power systems.

2.1 Power quality

In the area of power quality, several studies have been carried out to detect and locate disturbances using the wavelet transform as an useful tool to analyze interferences, impulses, notches, glitches, interruptions, harmonics, flicker, etc. of non stationary signals.

There are two main approaches to the harmonics and flicker field. The first one, carries out a multiresolution analysis (MRA) using wavelet filter banks in a first step and the application of the continuous wavelet transform to the subbands in a second step; the second one, uses a complex wavelet transform analysis or continuous wavelet.

Accordingly to the first approach, in 1999 is presented a study [5] to evaluate harmonics, developing an algorithm to identify all of them, including integer, non integer and subharmonics. In the first step of this approach, the frequency spectrum of the waveform is decomposed in two subbands using discrete wavelet packet transform filter banks with orthogonal high order Daubechies function. In the second step, a continuos wavelet transform is applied to nonzero subbands, achieving satisfactory results from a real test system. In later works [6]-[7], is presented an improvement to eliminate the effect of imperfect frequency respond of the filters in WT filter banks, and to better analyze subharmonics. [9]-[14] present a similar approach for harmonics and flicker analysis, respectively. Other similar work using different mother wavelets is presented in [11]. Accordingly to the second approach, [8] describes an harmonic analysis with a trapezoid complex wavelet function and the associated trapezoid WT. [15]-[16] show a flicker analysis using the Morlet and Gaussian continuous WT.

However, the effectiveness of wavelet transform for voltage disturbances studies is questioned in [10], pointing out that the STFT is more appropriate for these analysis with a properly chosen window size.

In power system disturbances field, the first works make use of WT to detect and locate various types of power quality disturbances, decomposing a disturbance into its wavelet coefficients using a MRA analysis technique. Santoso et. al. set up an investigation line on this area with the work presented in [33], then the authors in [25] make the proposal that, based on uniqueness of squared WT coefficients at each scale of the power quality disturbance, a classification tool such as neural networks may be employed for the classification of disturbances [28]-[29]. Moreover, in [26] develop an application to compress power quality disturbances signals

Other similar publications have been developed in this area [30-32].

However, the application of WT is not always adequate for the analysis of all types of disturbances, such as the case of voltage sag, as [22] points out, because the wavelet filter does not detect the voltage sag depth.

2.2 Partial discharges

The partial discharges are difficult to detect due to their short duration, high frequency and low amplitude signals, but the capacity of the wavelet transform to zoom in time the signals with discontinuities unlike the Fourier transform, allows to identify local variations of the signal. [36-40] applies these principles to detect partial discharges in transformers winding, cables and GIS (gas insulated substations).

2.3 Load forecasting

Demand forecasting is key to the efficient management of electrical power systems. The works have been developed for short term electrical load forecasting by combining the wavelet transform and neural networks. As electrical load at any particular time is usually assumed to be a linear combination of different components, from the signal analysis point of view, load can be also considered as a linear combination of different frequencies. Every component of load can be represented by one or several frequencies. The process decomposes the historical load into an approximate part associated with low frequencies and several detailed parts associated with high frequencies through the wavelet transform. Then, the forecast of the part of future load is develop by means of a neural approximation [42]-[43] or adjusting the load by a regression method [44].

2.4 Power system measurements

The advantage of using the wavelet transform for the application of power/energy and rms measurements is that it provides the distribution of the power and energy with respect to the individual frequency bands associated with each level of the wavelet analysis. There has not been much work on applying wavelet transform for rms voltage and power measurements. The discrete wavelet transform (DWT) algorithm for rms value of voltage or current and active power measurements is first introduced in the literature to achieve frequency separation into the various wavelet levels using IIR filters, [47]-[48], however provides non-uniform frequency bands which cannot be used to measure the rms value of voltage or current and power of individual harmonic components. In [46] this problem is solved developing a wavelet packet that can decompose a waveform into uniform frequency bands, so that this WPT algorithm has a capability to measure the rms value of voltage or current and power of individual harmonic components.

2.5 Power system protection

The potential benefits of applying wavelet transform for improving the performance of protection relays have been recognized in recent years [49-80]. In 1996, Chaari et al [71] introduce wavelets for the power distribution relaying domain to analyse transient earth faults signals in a 20 kV resonant grounded network as generated by EMTP; in the same year J. Momoh et al present an algorithm to develop a feature extractor suitable for training an Artificial Neural Network for fault diagnosis using the wavelet transform, in this case data was obtained from experimentation. At 1998 Magnago and Abur set up the development of a new investigation line in the area of fault location using wavelets, for this purpose, the fault generated travelling wave is processed by the wavelet transform to reveal their travel times between the fault and the relay locations; EMTP simulations are used to test and validate the proposed fault location. In 1999 the same authors extend the method to the identification of the faulted lateral in a radial distribution systems [65] and in 2000 present an improved method for their earlier papers [67]. Similar methods for fault location can be found in [66], [68].

High impedance fault identification [72]-[73]-[75] is other application area of wavelet transform, for example, in [75] Charytoniuk presents a comparative analysis for arc fault time location, frequency and time-frequency (wavelet) domain, the author demonstrates that the wavelet approach is strongly affected by the choice of a wavelet family, decomposition level, sample rate and arcing fault behaviour.

The application of wavelets to autoreclosure schemes [76]-[77] is develop to accelerate trip of power transmission lines, wavelet transform is adopted to analyse the fault transients generated by the secondary arc and permanent faults and the numerical results reveal that certain wavelet components can effectively be used to detect and identify the fault relevant characteristics in transmission systems and then to distinguish between transients and permanent fault.

The wavelet transform is also applied for the bars [49] , motors [54-57], generators [52]-[53] and transformer protection [58-63], in most of this cases, the spectrum of signals is analysed with the wavelet transform to develop online detection algorithm to detect insulation degradation, inrush and to carry out the precise discrimination between internal and external faults

2.6 Power system transients

In the mainstream literature, wavelets are first applied to power system transients in 1994 [17]. In this paper, the authors present a methodology for the development of software for classifying power system disturbances by type from the transient waveform signature. The waveform signature is derived from the wavelet transform of the transient signal. In 1996, Robertson, et al. [83] apply wavelet for the analysis of capacitor switching transients. The authors give a digital implementation of the wavelet transform via filter bank analysis and make clear that any valid wavelet can be used in this implementation.

Up to this point, the focus in the literature has been on identification methods. That is, identifying a transient disturbance and perhaps classifying it according to its wavelet spectrum. In [84], [86], Heydt and Galli propose the use of the Morlet wavelet as an *analysis* technique for power systems transients. The term *analysis* denotes the solution of voltages and currents which propagate throughout the system due to a transient disturbance.

In 2000, Meliopoulos [87], presents an alternative method for transient analysis of power systems, the method is based on the wavelet series expansion and reconstruction. The system matrix is developed by applying wavelet series expansion on the integro-differential equations of the power system. The procedure results in a set of algebraic equations for the entire network. The solution is in terms of the wavelet expansion coefficients of the voltages at the nodes of the network. The actual voltages can be reconstructed via the wavelet series reconstruction.

The transformer inrush identification based on wavelet [89]-[90] have the advantages that different kinds of inrush of the transformers can be correctly identified from different types of internal transformer faults; external transformer faults can be also distinguished from the internal fault.

Apart from, the application of wavelets to introduce new identification, classification and analysis methods such as those presented previously, at the moment is also studied the application of wavelets to develop new components models; for example in 2001, Abur et al. [92] extend the results of previous works [91] and describe a transmission line model which is based on wavelet transform taking into account frequency dependence of modal transformation matrices into the transients simulation. A different approach to the simulation of frequency dependence, untransposed transmission line transients is introduced. The effect of strong frequency dependence of modal transformation matrices on the transmission line transients is accounted for the time domain simulations via the use of the wavelet transform applied to the signals. This allows the use of accurate modal transformation matrices that vary with frequency and yet still remain in the time domain during the simulations.

3 CONCLUSIONS

This work carries out an approach on the wavelet application in power systems in order to facilitate the search of information in this area. So, it has been revised the last literature that exists in this field and made a classification of the different fields of power system applications. A brief description is included for each area to show the way as wavelet has been applied to solve some typical problems of power system protections, power quality and others. According to the authors of this paper's criteria, only some of the publications are presented due to space reasons; however, the full literature analysed, including the abstract, may be freely downloaded from http://dinel.etsii.upm.es/~hdiaz.

Since the analysis of the literature in wavelets application to power systems it could be concluded the following:

- The most of the application developments in this area use signal data obtained from a transient analysis program such as EMTP/ATP and a specialized wavelet program such as wavelet Matlab toolbox.
- One of the most promising developments in this area is the system relaying for high speed fault detection and localization.
- The field of wavelet application to power system is moving to build new models to analyse power system transients.
- The theoretical developments needed to further push forward the field is a methodology to choose the adequate mother wavelet for a specific application.
- Multiwavelets and second generation wavelets should be new approach to improve the actual and future applications.

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