Two applications for Power Quality Analysis using the Matlab Wavelet Toolbox

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Abstract. Nowadays there is an increasing number of electric and electronics equipment that has carried out a growing number of problems that affect to the power quality. Several studies on power quality have been made in order to detect and localise that kind of problems. For such objective it has been used the Wavelet Transform that allows the detection and localisation of disturbances in the voltage waveform. At laboratory level it is possible to use several tools, such as the Matlab Wavelet Toolbox that includes basic commands and a graphic environment. To begin with the study of this tool and its capability in detecting disturbances in the voltage waveform we need several test signals with known disturbances. This paper presents two applications developed for the study of Power Quality based on the Matlab environment.

Key words
Power quality, disturbances detection, wavelet analysis, wavelet transform, Matlab.

1. Introduction

In recent years, the power quality has been matter of several studies. But nowadays, the growing amount of electric and electronics equipment, such as personal computers [1], has led to an increasing number of problems that affect power quality [2] [3]. The disturbances that affect power quality range from undervoltages to harmonics, and many others, like flicker or transients [4]. This has led to a growing interest in the study of power quality.

Recent advances in signal analysis have led to the development of new methods for characterisation and identification of several kinds of waveform disturbances. Most of the effort in the power quality subject has been made in the detection and localisation of such kind of problems. The wavelet transform can be used to detect and localise several types of disturbances of the waveform. This mathematical tool is useful in the extraction of very important information from the distorted waveform.

Previously to the application of the wavelet transform to real signals we must carry out a study with a variety of signals, and it highly important that we know everything about them. So, in this sense, we need to generate several signals with known parameters like their amplitudes, frequencies and so on. Moreover, we need to be able to alter these signals with known disturbances. For such need we have developed an easy-to-use application.

In order to apply the wavelet transform to our test signals we can use several tools. One of these is the Matlab Wavelet Toolbox. This toolbox owns a powerful graphic environment, but for our purpose it doesn't fit all of our necessities, and it has some options that we don't need. For that reason we have developed another graphical environment personalised to apply only those commands from the wavelet toolbox that we need, and some routines that we can develop to apply to the signals and to the output from the wavelet transform.

This paper is organised as follows. In section 2 we present a brief introduction to the wavelet transform; in section 3 we explain how the test signal generator has been developed; section 4 is devoted to the graphical environment for the wavelet transform application and, finally, in section 5 we present the conclusions.

2. The wavelet transform

The integral wavelet transform of a function f(t) with respect to an analysing wavelet ψ is defined as

$$W_\psi f(b,a) = \int_{-\infty}^{\infty} f(t)\overline{\psi_{b,a}(t)}dt$$

where

$$\psi_{b,a}(t) = \frac{1}{\sqrt{a}}\psi\frac{t-b}{a}, \quad a>0$$

The parameters b and a are known as translation and dilation parameters.

The integral wavelet transform provides a time-scale analysis, but by mean of the proper transformation we can get something like a time-frequency analysis.
As happens with the Fourier Transform, we have the discrete wavelet transform (DWT). The integral shown in the expressions above becomes

$$W_{\psi} f(k2^{-s}, 2^{-s}) = 2^{s/2} \int_{-\infty}^{\infty} f(t)\psi(2^{s} t - k)dt$$

Discretizing the function f(t) and assuming a sampling rate of 1, for simplicity, we have that

$$W_{\psi} f(k2^{-s}, 2^{-s}) \approx 2^{s/2} \sum_{n} f(n)\psi(2^{s} n - k)$$

One important characteristic of this expression is that to compute the wavelet transform of a function at some point in the time-scale plane all we need is the function at those values of time at which the wavelet is nonzero [5].

3. Disturbed signal generator

To get some conclusions from the results that give the application of the wavelet transform, it is necessary to have several test signals altered with completely known disturbance (type and characteristics). So, in this sense, in the first level of our laboratory studies, we have developed an easy to use graphical environment that allows us to generate such signals and apply them disturbances.

Because we are going to work with the Matlab Wavelet Toolbox we decided to develop our "disturbed signal generator" using Matlab too. Figure 1 shows the graphical environment that we have named "Perturba".

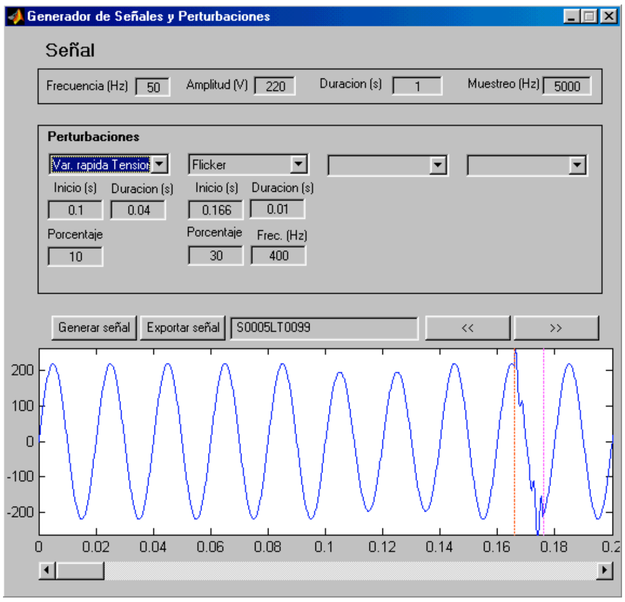

Fig. 1. Disturbed Signal Generator (Perturba).

Since the typical voltage waveform is a sine signal with a frequency of 50 Hz, it will be the "mother signal" that will generate the program. A later aim of our study will be to validate the conclusions obtained from the application of wavelet transform to real signals. In this sense, it is very important to have the possibility specifying the sampling frequency of these test signals, due to the wide range of commercial equipment available for test and measurement and their variety of characteristics. For that, our application allows us to specify this sampling frequency. An advantage of such characteristic of our application is that we could observe the influence of the sampling frequency in the results obtained, for example.

This graphical environment has been designed to apply the most common types of disturbances in power quality. That is:

- Frequency variations.
- Slow and fast voltage variations.
- Flicker.
- Dips, sags and swells.
- Transients.
- Harmonics.

This program work as follows. First, we must specify the frequency, amplitude and duration of the "mother signal", and the hypothetical sampling frequency. The default values are 50 Hz, 220 V, 10 seconds and a sampling frequency of 1000 Hz. We can see in the detailed figure 2 that the signal duration must be specified in seconds.

Fig. 2. Parameters of the "mother signal"

Once we have determined the mother signal, we must specify the disturbance or disturbances that affect to this signal. In this sense, we can apply it up to four different disturbances. For each disturbance we must specify several additional parameters, such as the time in which the disturbance begins, its duration, amplitude, order or frequency. The most important of these parameters will be the beginning and duration time, because they will be the key data to check if the wavelet transform is able to detect the point in which the disturbance happens. In figure 1 we can see an example in which the pure signal is affected by two different kinds of disturbances. In figure 3 and 4 we have specified different disturbance in order to show their characteristic parameters.

Fig. 3. Example of different disturbances

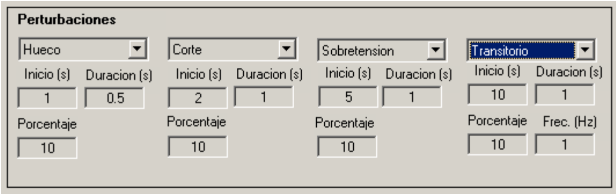

Fig. 4. More disturbances

After that, once we have specified one or several disturbances, we will proceed with the generation of the signal. For that purpose we need to use the lower part of the main window of "Perturba". Here, can generate the disturbed signal only by clicking on the button "Generar señal". This action generates the signal and plots it in the figure of the lower part of the window, as shows figure 5. To see the parts of the signal in which we are interested we have a scroll bar below the figure and two buttons to perform a "page scroll" of the figure.

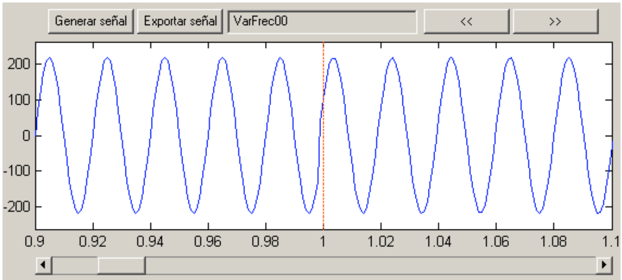

Fig. 5. Plotting a signal with one disturbance.

Finally, we need to export our signal in ".mat" format, because this is the input format of the program that applies the wavelet transform. "Peturba" allows us to specify a name for the file in which the generated signal is going to be stored. In figure 1 and 5 we can see two examples in which we specify a name for the .mat file.

4. Applying wavelet transforms

Locating the time in which the disturbances occur is one of the capabilities of the wavelet transform in power quality. To identify this time we could apply the following steps:

- Generate a set of test signals with known disturbance beginning and duration times.
- Apply the different wavelet transforms of the Matlab toolbox to this set of signals.
- Try to identify the location of the disturbance by means of a visual inspection of the wavelet coefficients, for example.

Let us see it with an example. Suppose that we have generate a signal with "Perturba". This signal has the following characteristics: frequency of 50 Hz, 220 V of amplitude, duration of 2 seconds and sampling frequency of 5 kHz. To this signal we have applied a frequency variation of -1% in t=0,2 seconds with a duration of 0,1 seconds. We can see in the figure 6 that this kind of disturbance is visually imperceptible.

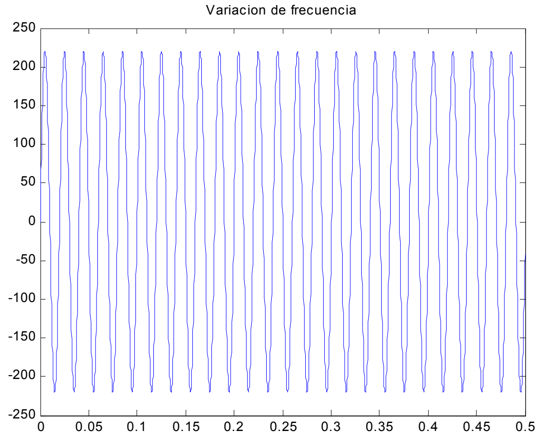

Fig. 6. Signal with frequency variation.

After that we can proceed applying to this signal the different wavelet transforms. For instance, if we choose the "Haar" wavelet transform, at detail level 1 we get something like the graph shown in figure 7. It is obvious that we could determine the time in which the disturbance appears, but not when it ends. So, in this sense, we'd conclude that the Haar wavelet at level 1 isn't good enough in order to detect such kind of disturbance.

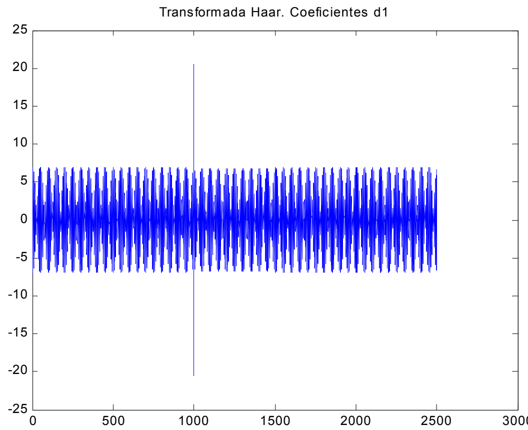

Fig. 7. Detail coefficients level 1. Haar wavelet.

Now, instead of the Haar wavelet, we could choose to apply the "Daubechies" wavelet. We can see the details coefficients of level 1 in figure 8. Clearly we could determine the time in which the disturbance appears and disappears because there are two maxims of the coefficients in such times.

To get these detail coefficients we can simply use the correct commands provides by the Matlab wavelet toolbox. For the example we have exposed above, we need only three lines of Matlab code to get the detail coefficients vectors. These could be something like this:

```
l_s = length (s)
[C,L] = wavedec (s, Level, Transform)
Coef = wrcoef ('d',C,L,Transform, Detail)
```

In the "Coef" variable we will obtain the mentioned coefficients vector, which we have plotted in figure 8.

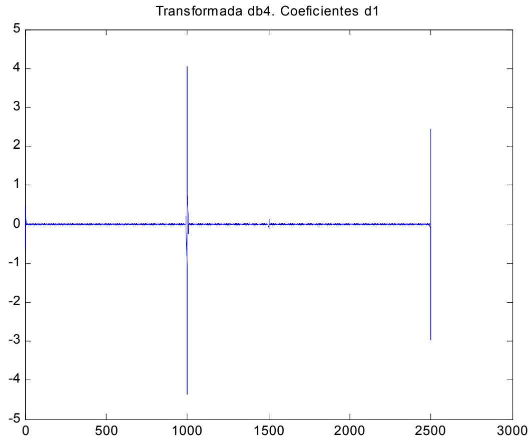

Fig. 8. Detail coefficients form Daubechies wavelet.

Although the visual inspection of the detail coefficient vectors obtained from the application of different wavelets was one of the first methods used, it is not very useful. Instead of that, we can use several methods proposed by different authors, like the inspection of the squared wavelet coefficients (SWC) and the energy curve of the signal given [6]. So, in this case, we need to apply some additional treatment to the data obtained from the wavelet transform through a specific algorithm.

According with that necessity we have developed another easy to use application that allows us to apply the following procedure:

- Choose a file with the signal under test.
- Select a wavelet and obtain the desired coefficients vector.
- Apply an algorithm to the coefficients vector in order to obtain useful information.

This application has been developed using Matlab and its Wavelet Toolbox. Figure 9 shows the graphical environment developed for the above procedure.

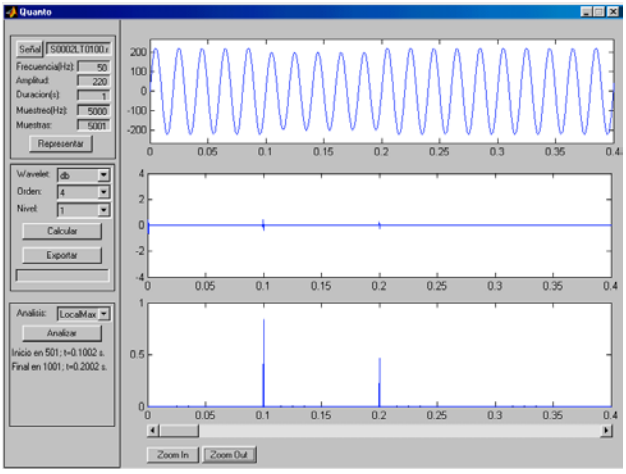

Fig. 9. Graphical environment for wavelet.

This application has been developed trying to make the task as easier as possible, in order to get a tool to rapidly perform a lot of tests to signals. It consist of three regions in the left part of the window shown in figure 9. The first allows us to select the test signal and display it in the upper right part of the window.

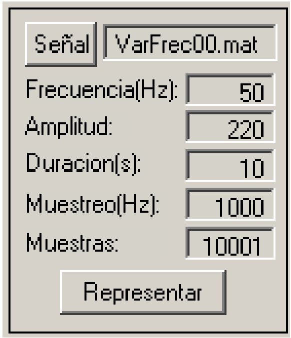

Fig. 10. Parameters of the selected signal

The second part on the left side is for selecting and applying of wavelet transforms. We specify in this case the transform to be applied, it order and the level of the detail coefficients we desire to study.

Fig. 11. Wavelet transform to be applied

In figure 11 we see that we can export the detail coefficients vector to a file, in .mat format.

And finally, the lower part of the window allows us to choose some specific algorithm to apply to the vector of coefficients given by the wavelet transform. In case this algorithm would produce a graphical output we could see it in the lower left part of the window.

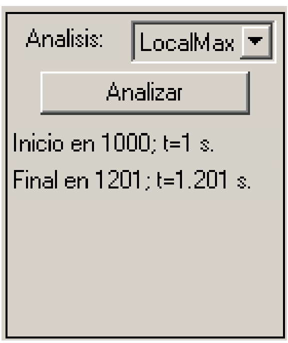

Fig. 12. Applying a specific algorithm.

Using this new tool we can easily perform several analysis to all the test signals we generated with "Perturba". For instance, choosing the analysis "LocalMax" shown in figure 12, we obtain the beginning and ending time in which the disturbance occurs. If we design another algorithm, we only have to add its code to the .m file of the application, and then we can apply the new algorithm to the test signals.

In figure 13 we see an example of other signal affected by disturbances.

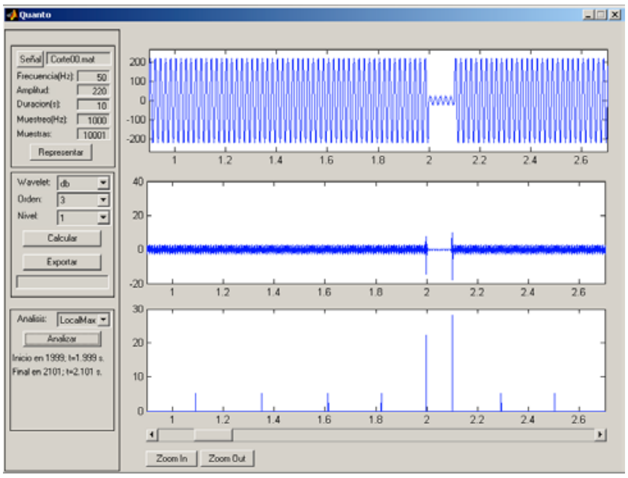

Fig. 13. Example of signal and disturbance.

5. Further Information

Questions concerning the functionality and use of the applications described in this paper may be addressed to the following address:

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6. Conclusion

In order to study the usefulness of wavelet transform in power quality we have the possibility of using the Matlab Wavelet Toolbox. The repetitive procedure of load a signal, do the different wavelet transforms and finally apply some specific algorithms to the coefficient vectors make it very tedious. To simplify that procedure we have developed two simple but efficient applications under Matlab. The first one allows us to have a set of signals with known disturbance, what we think is extremely important in the first stage of the study. The second application, devoted to simplify the above procedure, is as useful and important as the first.

In the opinion of the authors, these applications have proved their effectiveness through the first studies accomplished with a set of more than one hundred signals. The main benefits of both application is the huge time saving in the studies we need to do.

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