TRANSIENT DISTURBANCE RECOGNITION FOR POWER QUALITY ANALYSIS

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ABSTRACT

This paper presents a computational tool to assist in solving problems related to power quality, responsible for the analysis of situations caused due to possible disturbances originated in different processes, either in the power network or in the customer facilities. The analysis is carried out based on information collected from a repository of waveforms, which is linked to the power quality monitoring system of a utility. The computational tool includes a specific module designed for the recognition of similar transient disturbances in a waveform database. The proposed selection algorithm is based on the energy of the decomposition coefficients of the wavelet transform, on the RMS value, the duration of the disturbance and the Euclidean distance, from which one is able to generate differentiated patterns or signatures. Some illustrative examples are presented in the paper. Results related to the application of the proposed methodology as well as perspective of future applications and conclusions are then discussed.

INTRODUCTION

Many studies developed around the world have shown that billions of dollars per year related to commercial, financial and technical losses are associated with power quality (PQ) [1]. In Brazil, utilities and regulators are mobilized to measure the financial impact related to these phenomena. Moreover to diagnose and mitigate the consequences of disturbances, one should measure and evaluate the technical and economic losses related to this matter. All actors in the electricity sector must act by consensus, since the parties involved, such as utilities, customers and manufacturers have already lost a lot due to the deregulation and the current lack of effective actions.

Currently, it is noticed an increasingly amount of requests from customers, with facilities sensitive to PQ disturbances, which require performance on continuity and compliance of the power supply to meet the established standards. In addition to it, the issuing of the distribution proceedings – PRODIST (Brazilian Power Distribution Standards), have set and limited power quality indices, what have caused an alert to all industry agents. On the utility side, the control of PQ will be affected substantially on the connections with customers. On the manufacturer side, it will be noticed an improvement in equipment design and on the information regarding sensitivity of the equipment and processes. And, by the client side, it will act mainly on the knowledge of the problem, its causes and responsibilities. However, many customers are not aware that the problems on the interruption of industrial processes are caused by electrical phenomena related to the voltage waveform (transient voltage, short-duration voltage variations (SDVV – voltage sags and swells), harmonic distortion, unbalance, etc.). Furthermore they might be originated in the distribution system or in the customers´ internal facilities. In addition, other important facts to be highlighted are as follows:

- The major part of these problems occurs due to internal causes in the customer facilities
- Not always the solution is dependent only on the power company
- The solutions may be more than one, these require alternative investments by the customer
- Depending on the action studied and well-directed, actions taken within their facilities could allow a rapid return on investment.

This research concerns the development and implementation of a methodology for disturbance recognition. A computational tool recognizes transient events similar to the event in analysis, such as SDVVs, switching capacitors, etc. Thus, a waveform record may be recognized as similar to one or more records stored in a large repository of existing fault occurrences in a real database. In this work, it is assumed that each disturbance has a feature that makes it distinct from others, like a signature or fingerprint that provides its recognition.
This tool allows one to analyze PQ disturbances. Whenever a waveform is identified in the repository bearing the same signature as the one under investigation, one can make use of the analysis performed earlier (history of actions taken to solve the problem), i.e. using consolidated information to a new analysis. In the process of recognition of fault occurrences and correspond collected waveforms, decomposition algorithms are developed for identification and comparison of waveforms, which incorporate the wavelet transform (WT), the RMS value and the Euclidean distance.
The paper is divided into the following sections: Section II focuses on the state of the art in characterization and classification of PQ disturbances. Section III presents the methodology utilized in the extraction of patterns used for recognition of similar transients. Simulations and results are presented in section IV and finally, section V outlines the main conclusions.

STATE OF THE ART IN CHARACTERIZATION AND CLASSIFICATION OF PQ DISTURBANCES

This literature review considers, on one hand, TW and RMS values in the analysis of disturbances, since studies developed worldwide show good results to get patterns to characterize transient events. On the other hand, other types of transformations are also used, such as fast Fourier transform (FFT), for example, which are mainly used for analysis of steady state disturbances and the windowed FFT, which is utilized both for transient and steady state events. Well-known techniques such as artificial neural networks (ANN) are important in classification. Fuzzy logic and support vector machines (SVM) are being implemented showing satisfactory results. This item briefly presents some works related to feature extraction of PQ disturbances and their subsequent classification.

In reference [2], it is mentioned the potentiality of signal processing techniques in power systems, especially in PQ. This article examines and discusses a lot of previous papers related to PQ diagnosis. It presents real examples of power system problems that involve changes in voltage and current, which include: interruptions, short and long duration voltage variations, harmonics and inter-harmonics, and electromagnetic transients.

Different techniques for detection, segmentation, characterization and classification are shown in [2], highlighting the advantages and disadvantages of the methods used. Among the identification methods are: WT, RMS value, FFT, Kalman filter, and the Hilbert and Clarke transformations. Likewise, for classification, the paper presents methods based on rules and on statistics (ANN, SVM). The subject of this paper is to seek the underlying cause of events, for which they are studied in 3 different groups: rectangular voltage dips, nonrectangular voltage dips and step changes in voltage.

In addition to what is presented in [2], other studies show similar goals [3]- [7]. For example, reference [3] emphasizes the segmentation in time using different methods such as residual voltage, RMS, derivative and Kalman filter. They mainly use basic features to classify events using two methods, based on rules and support vector machines. References [4] and [5] focus almost on the same characteristics.

On the other hand, reference [8] uses the Multiresolution Analysis (MRA), with the mother wavelet Daubechies 4 (db4) to detect and locate various types of PQ disturbances, and extract features for the classification.

Moreover, TW is used in [10] for the classification of disturbances, with the Morlet function. Reference [9] extracts frequency components from 60 and 600 Hz. The 60Hz component indicates variations in amplitude and the 600 Hz indicates transient variations.

Reference [11] uses the db4 in order to extract features of transient events and TF to characterize steady state phenomena. The research developed in [12] also use the same function for the wavelet decomposition and presents a methodology that detects, locates and classifies the possible disturbances occurring in a (PCC) busbar.

Reference [13] proposes three strategies for identifying patterns related to PQ disturbances. These strategies use the TWD and the RMS value. The TWD strategy allows decomposing a signal into different energy levels, which are used to characterize the disturbances bearing information on the frequency domain. In this study four wavelet mother function families were used (Daubechies, Biorthogonals, Coiflets and Symlets). The Biorthogonal function provided a better result. The RMS value was used to characterize the disturbances with changes in magnitude. The patterns obtained are classified using SVM.

Wavelet Decomposition Technique

From the Wavelet Transform theory, it is possible to separate frequency components of signals using wavelet decomposition filters [13]. The result using the high-pass decomposition filter gives what is known as the detail coefficients in wavelet domain, and the sequences in detail in the time domain. In the same way, when using low-pass decomposition filter, the corresponding coefficients lead to sequences of approximations respectively.

The filtering process in three consecutive levels can be seen in Fig. 1 using an oscillatory transient as example.

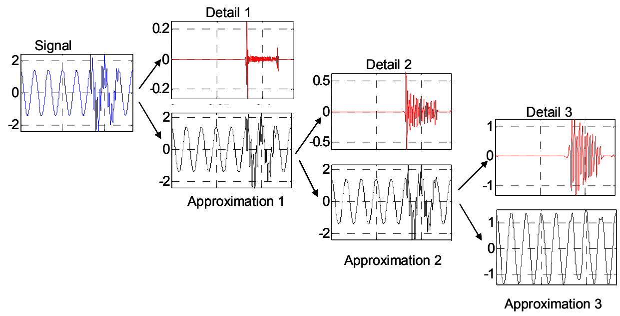

Fig. 1. Decomposition of oscillatory transient.

The separation of the frequency components of a signal allows characterizing it, giving the possibility to generate easily identifiable patterns that can be classified later.

DISTURBANCE RECOGNIZING METHODOLOGY

The feature extraction allows one to obtain patterns that help to characterize the disturbance. This paper uses wavelet decomposition and RMS value for such a characterization. Later the Euclidean distance is used to find the similarity between two given waveforms taking into account 3 phases. Finally, the duration of the disturbance allows enhancing the disturbance recognition process. This simple method allows one to find several waveforms similar to the one investigated in a fault recording database. Fig. 2 illustrates the disturbance recognition system scheme with corresponding basic elements.

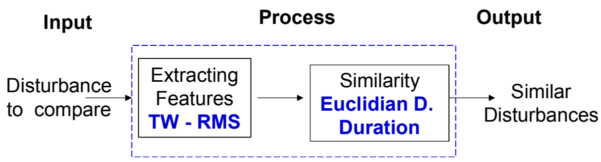

Fig. 2. Disturbance recognition scheme.

Input : disturbance

In the Fig. 2 the system input is the disturbance identifier (ID) and the desired quantity of similar items in the disturbances database (DDB). Each disturbance comprises waveforms that represent the voltages in a three-phase 13.8 kV system. The waveforms are captured with 128 samples/cycle (60 Hz) and a total of 30 cycles of signal per event. In the DDB, each waveform is recognized by its identifier or ID. Besides that, other information such as event date, magnitude, etc. are available as well.

Process : recognition of similar disturbances

The disturbance recognition system comprises two steps:

a) Extracting features: WT is used to feature extraction together with RMS value. By means of the energy of the decomposition coefficients in the wavelet transform it is possible to separate and extract information of different spans of frequency. In this study, Biorthogonal 6.8 is used as the mother wavelet function to generate the decomposition filters according to [14].

After the decomposition and energy coefficients calculated in 7 detail levels, a 7 position vector is determined for each voltage phase. Furthermore, two other parameters, namely max RMS and min RMS, are obtained as follows:

- *max RMS*: difference between the maximum RMS value of the disturbance and the mean value of the RMS value of pre-event.
- *min RMS*: difference between minimum the RMS value of the disturbance and the mean value of the RMS value of pre-event.

Using the vector with 7 positions (energies) and the two RMS based parameters, a new 9 position vector is generated as a pattern. Fig. 3 shows a representation of such a vector.

Fig. 3. Pattern vector obtained from wavelet energy and max-min RMS values

Three pattern vectors (for each phase) are stored in a signature database, namely SDB. This database stores other information as well such as event duration, event type, ID and date of occurrence.

Fig. 4 shows the transformation of all waveforms from the DDB to signatures in the SDB.

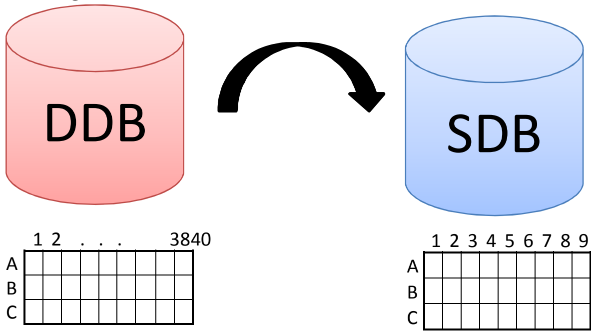

Fig. 4. Transformation from sampled waveforms to signatures.

b) Similarity: in order to obtain the similarity among two or more signatures, the Euclidian distance (ED) is calculated between each vector until the minor distance that represent the major similarity is found.

The signature vector of reference is compared with all signatures of the SDB, provided it meets the following conditions:

- Must be in the range of analysis (period of time given by initial and final date)
- Disturbance in the database is related to customer complaints or other incidents in one or more users.

Finally, IDs are sorted in ascending order by using the Euclidean distance calculation. The event duration is used to refine the similarity between the signatures.

SIMULATIONS AND RESULTS

The disturbance recognition system was implemented in Java and C++, using Netbeans® 6.7 and Borland C++ builder® 6.0, respectively. However, the algorithm was developed initially in MatLab® 7.0 for quick validation of the method.

Fig. 5 shows example 1 shows two similar disturbances by using the proposed method. The top waveform, with ID 571, represents the one under investigation. The most similar waveform in the database, according to the method herein presented, corresponds to waveform ID 383, shown at the bottom of the same figure. In this example the duration of the disturbance is not considered.

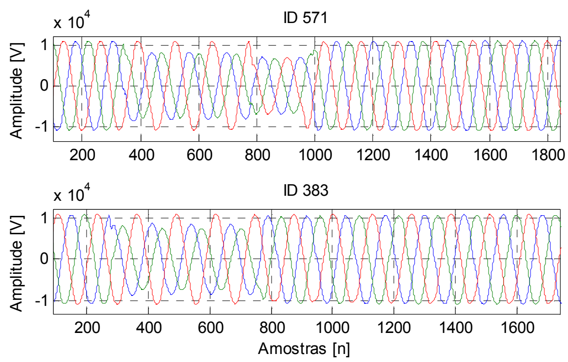

Fig. 5. Example 1: obtaining a similar disturbance.

Fig. 5 shows that both waveforms present two phases with the same fault amplitude, but different duration.
Several tests were carried with the implemented system showing satisfactory results.
Fig. 6 presents a second example of a double-phase fault leading to an interruption. Despite waveforms have the disturbance at different phases, the algorithm determines a clearly similar disturbance.

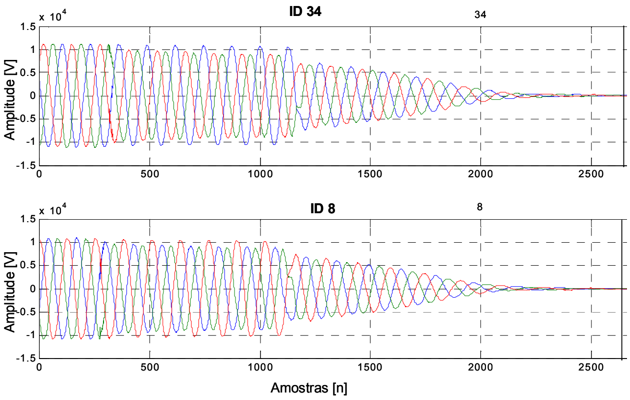

Fig. 6. Example 2: obtaining a similar disturbance.

Event duration was incorporated in the in the disturbance recognition system for example 2. One can perceive that both disturbances are similar and have very similar duration times.

CONCLUSIONS

Feature extraction algorithms were implemented to obtain patterns using the Multiresolution analysis that WT offers throughout the energy of the detail decomposition coefficients. Besides that, RMS value allows one to extract disturbance features related to changes in magnitudes. Both methodologies together create a suitable pattern for identification.

The model was implemented in Matlab®, Borland® C++ and Java to find similar transient disturbances in a real waveform data base for a large electric power distribution company in São Paulo - Brazil. The algorithm implemented recognizes the similar disturbances independently of the phases order. This algorithm can even allow one to verify the correct connections of PQ monitors installed in the electrical system.

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BIOGRAPHIES

Valdomiro Vega García graduated as Electrical Engineer ('04) and Master in Engineering ('07 scholarship UIS) from Universidad Industrial de Santander, Bucaramanga - Colombia. He is now a Doctorate candidate at the University of Sao Paulo, where he holds a scholarship (CAPES). He is a Student Member of IEEE and CIGRE. He is a PhD researcher in ENERQ – Center for Regulation and Power Quality Studies. His areas of interest are Signal processing and Power quality.

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